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EnergyTransition 2012\2020\2050

Strategies for the Transition to Low Energy and Low Emission Structures

February 2011

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Strategies for the Transition to Low Energy and Low Emission Structures

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Abstract

The project EnergyTransition analyses options to comply with the targets of the EU Energy and Climate Package in an inter-disciplinary approach. 25 storylines and technology wedges are developed and analysed in a bottom-up approach starting from energy services. The technology options are analysed with respect to their effects in the energy system as well as with respect to their effects on energy flows and emissions. The analysis of changes in the energy system is complemented by an economic analysis comprising an input-output analysis in order to reflect employment and output effects from the investment phase and an analysis of changes in operating costs due to the technology wedges. A microeconomic cost approach for selected technology wedges complements the analysis.

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Part A

Part B

Part A

1 Characteristics of an integrated energy system

1.1 The need for a new look at energy systems

In a statement Joseph Stiglitz, head of the Commission on the Measurement of Economic Performance and Social Progress initiated by the European Commission, concludes that "Our statistical apparatus, which may have served us well in a not too distant past, is in need of serious revisions" (*CMEPSP*, 2008). Applied to our understanding of energy systems this means a redirection from the focus on energy flows to energy services. Not the quantity of energy demanded by households and companies is generating welfare but the energy services delivered. Energy services can be classified according to the categories:

- Thermal services for heating of buildings and thermal services for production processes
- Mechanical services for mobility and stationary engines
- Specific electrical services for lighting, electronics and other appliances

Energy flows are on the one hand determined by the amount of energy services needed and on the other hand by application and transformation technologies used. The wide range of available technologies and of primary energy sources thus opens a spectrum of options, which result in different amounts of energy flows and greenhouse gas emissions (GHG).

Thus a fundamental analysis of a reorganisation of the energy system needs to focus on energy services.

1.1.1 Technologies for the enhancement of energy productivity

Efficient technologies that increase energy productivity are available for the central areas of energy services. Well known examples are:

- Retrofitted buildings providing the same energetic comfort with a need of only about a quarter of the energy flows compared to the status before thermal insulation.
- New buildings based on passive house standard that need only one tenth of energy flows compared to the average of the housing stock.
- The transition from combustion engines to electric engines in vehicles is associated with a quadrupling of energy productivity.
- Highly efficient co-generation in combination with heat pumps can enhance energy efficiency by factor 4.

The strategies to considerably improve energy productivity are a necessity to reduce fossil fuel use. This is underlined by the limited availability of renewable energy sources. A policy framework initiating ambitious improvements in energy efficiency seems thus indispensable.

1.1.2 Challenges for energy and climate policy

EU member states and hence Austria are confronted with three objectives for energy and climate policy:

- For 2008-2012 the Kyoto goal applies for Austria with the obligation to reduce GHG emissions by 13% compared to 1990 emission level. If emission reductions are not achieved on the national level Austria has to buy emission rights from abroad generated by the Kyoto-instruments Joint Implementation or Clean Development Mechanism.
- In December 2008 the EU Council and the EU parliament agreed on comprehensive energy and climate goals for 2020. The respective goals for Austria stipulate to increase the share of renewable energy in final energy demand to 34% until 2020 and to reduce GHG emissions in sectors not covered by the EU emissions trading system (EU ETS) by 16% compared to 2005 emissions. The overall EU goal for installations covered by the EU ETS is a reduction of emissions of 21% compared to 2005 levels. The sectoral and national goals are compatible with an EU wide emission reduction of 20% compared to 1990 emission levels. In case non-EU member countries oblige to emission reduction targets after 2012 the EU considers a reduction target of 30% until 2020.
- Discussions for long term energy and climate goals until 2050 started within the EU. In order to limit global temperature rise to 2°C compared to the preindustrial level, the EU acknowledges that greenhouse gas emissions need to be reduced by 80%-95% by 2050 (European Council, 2009).

The consensus on the EU energy and climate package was not only motivated by climate change issues but also by the increasing dependency on energy imports from regions characterised by political instability. The only way out of this dependency is an increase in energy productivity linked with a stronger focus on renewable energy.

The ambitious but well defined objectives need to go along with a new understanding of energy systems. The EU goals for 2020 clearly outline the perspectives for the development of energy systems.

The challenge is to find structures that are compatible with the goals for emission reductions and the share of renewables in final energy demand in 2020. From 2020 as starting point development paths need to be traced back to the existing energy system. In this sense a backcasting strategy needs to supplement decision processes that are based on forecasting energy structures from past experience.

1.2 A new concept of the energy system

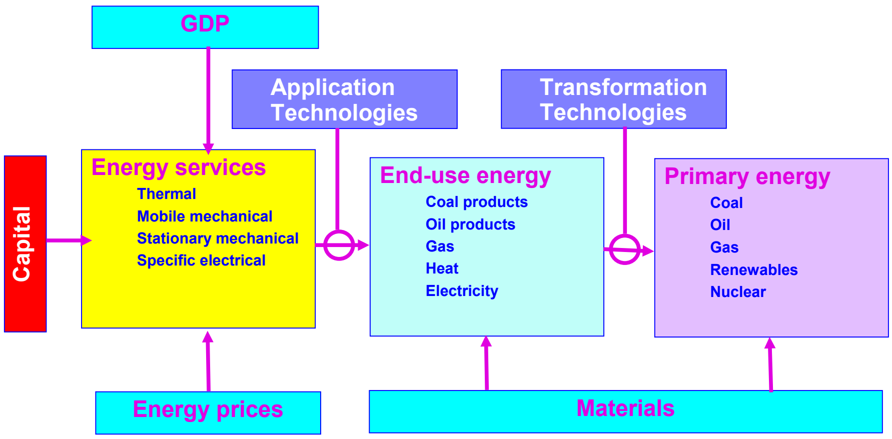
1.2.1 Energy services, application and transformation technologies

The analysis of energy systems usually focuses on observable energy flows, from primary energy sources to the demand of final energy by households and companies. This approach is of limited use with respect to the following questions:

- What energy services will be needed in the future?
- How can the related energy demand be satisfied?

New concepts of the understanding of the energy system aim at expanding the analysis of energy flows through a closer look at the technological "black box". This allows identifying essential characteristics that describe the causalities within the energy system. An illustration of this approach is given in Figure 1.1.

Figure 1.1: Structure of energy systems



Source: Own illustration.

1.2.2 Energy Services

The starting point are energy services for households and companies representing the quality of the underlying energy system. Three types of energy services can be distinguished:

- Thermal energy services on different temperature levels comprise low temperature needs in buildings to high temperature needs in industrial processes.
- Mechanical energy services are used on the one hand for vehicles to satisfy mobility needs and on the other hand for stationary engines in households and companies.
- Specific electric energy services for lighting and electronics.

The volume of these energy services is influenced by the volume of economic activity (approximated by Gross Domestic Product) and mirrors economic welfare. Examples for energy services would be room cubature at a specific temperature, a person's access to other people and goods, lighted areas and the use of electronic appliances. As energy services are usually not measured directly nor available in statistics, proxies have to be used in the quantitative analysis e.g. yearly kilometres driven.

Considering these energy services the first step is the assessment whether there exist potentials for a reduction of the service volume as measured by the proxy at a constant welfare level. This could e.g. be achieved by improved spatial planning or improved mobility management. This means for mobility services the same access level to goods and persons at a lower level of yearly kilometres, or for thermal services reduced heating in non-used rooms to achieve the same welfare level with lower energy use.

Statistical databases usually lack information on both energy services and the actual welfare relevant service generated by them, indicating the need for an improvement in data availability for modelling energy structures.

1.2.3 Application technologies and final energy consumption

The demand for energy of households and companies in order to provide energy services depends on the application technologies used. In buildings e.g. the energy required to deliver the energy service room temperature depends on the thermal quality of the outer shell of the building. With respect to mobility services the design of vehicles (e.g. lighter weight through use of polymers) and the choice of the propulsion systems (electric engine versus combustion engine) are of relevance.

Which application technologies are available and which are chosen in an investment decision depend on the one hand on the prices for energy and the technology and on the other hand on institutional factors. That is building codes or mobility management strongly influence technology choices.

1.2.4 Transformation technologies and primary energy demand

Energy sources for final energy consumption typically result from transformation processes with primary energy sources as input. Both, the transformation process and network distribution are associated with losses. Thus at this level of the energy system decisions about transformation technologies, the primary energy sources used and the structure of the distribution network are of crucial importance. Instead of stand-alone generation of heat or electricity one can aim at a combined production with co-generation technologies. For thermal processes the size and use of the co-generation technology is directed at the heat requirements of the thermal process. With respect so the choice of primary energy sources the requirement for GHG emission reduction needs to be taken into account. This supports energy sources with a low carbon intensity and an increased use of renewable energy sources.

These technological trends in transformation technologies have consequences for distribution networks. The existing network structures are increasingly complemented and in the future even substituted by decentralised and interactive structures. This would mean that the differentiation between energy producers and energy users is removed when decentralised installations from households and companies feed into the grid.

1.3 Criteria for technology choices

The structural understanding of energy systems described in the previous section shows that the required energy services can be supplied by a wide spectrum of energy sources both concerning the quantity and the type of energy. The question then remains what criteria are relevant for concrete technology choices.

One way is to discriminate between choices according to price differentials. As recent developments in energy prices – especially fossil energy – show, prices are increasingly volatile and do not necessarily reflect physical scarcities. Furthermore new technologies that are costly today may prove cheap in the future when costs decrease through learning and higher market diffusion[1]. Thus volatile prices are an inadequate decision criteria for investment.

1.3.1 Technical criteria

Technical criteria for technology choice can be derived from the laws of thermodynamics. The first law of thermodynamics basically states that energy can be transferred from one system to another in many forms. Efficiency is aimed for in the sense that output is maximised for a given input in the transformation and application process. This reflects a quantitative efficiency criterion.

The second law of thermodynamics addresses exergy efficiency in the sense of maximum use of work of an energy source. This qualitative criterion points at using energy sources according to their maximum work capacity that is electricity or natural gas should not be used to generate low temperature heat as this results in a qualitative efficiency loss.

1.3.2 Economic criteria

Economic criteria emphasise the evaluation of the total system involved in providing energy services. Looking again at the example of heating in buildings it could turn out that the cheapest option is a passive house standard linked with solar panels and photovoltaics in order to satisfy the low residual energy demand. Under certain conditions this option can be more cost efficient than buildings with a less ambitious energy standard and a heating system like district heating or natural gas.

1.3.3 Ecological criteria

The use of fossil energy sources has serious impacts on global ecosystems and global climate change. Besides the depletion of oil and gas and the insecurities in supply due to strategic

[1] This can be observed e.g. for energy efficient construction.

scarcities the effects of climate change are an additional motive to reduce the use of fossil energy sources.

1.4 Strategic guidelines for restructuring the energy system

From the above one can summarise and identify three strategies that could serve as guiding principles for restructuring energy systems:

- Low energy
- Low carbon
- Low distance

Low energy needs to be dealt with as first priority in a restructuring process. It addresses any activities that aim at providing energy services with less energy flows. This includes the elimination of redundant energy services (e.g. in terms of person kilometres but not the access to goods and persons) just as well as innovations that improve the efficiency of transformation and application technologies.

Low carbon takes up a controlled phase-out of fossil energy which is not only advised because of climate change but also because of energy security issues. This strategy can only be achieved in combination with a substantial improvement in energy efficiency. An easy one to one substitution of fossil energy by renewables is not feasible due to limitations in the availability of renewable energy.

The guiding principle *low distance* relates to the local availability of renewable energy sources which opens the opportunity of small scale installations. A stronger orientation to local supply needs to go along with new network structures for electricity and heat.

2 The extended concept of technology wedges

2.1 The Pacala-Socolow approach

Climate protection is the global challenge for the environmental policy of the 21st century. The fact and causes of global climate change have been clearly established. Anthropogenic emissions mainly from the combustion of fossil fuels[2] are primarily responsible for the continuous increase in the concentration of greenhouse gases in the atmosphere and therefore for global warming. Their impact will change many natural, physical and biological systems in the future which will result in increasing temperatures, changing precipitation patterns and the changing frequencies and intensities of extreme weather events (Stern et al., 2006; IPCC, 2007) with effects on ecosystems, food production, water supply, health and economic development. On the one hand, the changes in natural conditions require adaptation measures to reduce the risks. On the other hand, it is necessary to avoid an

[2] CO_2 emissions have a share of 77% in global GHG emissions (Stern, 2006).

uncontrollable climate change by implementing measures for the reduction and avoidance of greenhouse gas emissions.[3]

Technological developments are still seen as a central aspect to achieve the goal of stabilising greenhouse gas concentrations in the atmosphere (cf. e.g. Grubb, 2004; Pacala – Socolow, 2004; Murphy et al., 2005; Fischer-Newell, 2007; Fischer, 2008). However, this will require an extensive and fundamental restructuring of the current system of energy generation and consumption. Although currently available technologies can already contribute to a clear reduction of emissions in the short term, an expansion of the technology portfolio and therefore early investment in research, development and innovation is required in the long term.

Pacala and Socolow (2004), Hotinski et al. (2004) show that a stabilisation of global greenhouse gas emissions[4] using existing technologies is possible in the next 50 years and that a broad diffusion of innovative technologies is required afterwards to reach the concentration goals. Each of the technology categories that are available in the short term – even if some are not yet broadly diffused and cost intensive – can make a significant contribution to the mitigation of emissions on a global level. A broad spectrum of measures is considered that comprises energy efficiency improvements in buildings, transport and energy generation, a reduction of the emission intensity of energy generation (natural gas instead of coal, renewable energies, nuclear energy), carbon capture and storage as well as reforestation measures.

According to Pacala and Socolow (2004), the challenge consists in the broad application and a large scale up of the available technologies on the one hand, and in the initiation of climate-relevant research and development (R&D) on the other hand.

Starting from historical emissions the concept of stabilisation wedges presumes a Business as Usual (BaU) path for emissions. In this BaU scenario an improvement in energy efficiency and a decrease in carbon intensity of primary energy are assumed along rates experienced in the past. The scenario is contrasted by a stabilisation path for emissions (see Figure 2.1). The area resulting from the deviation of the BaU from the stabilisation path comprises the so called stabilisation triangle illustrating necessary global emission reductions. These reductions can be achieved by deployment of largely existing technologies until 2050. Out of fifteen technology options a portfolio of seven equally sized technology wedges was formed, each achieving an emission reduction of one GtC per year after 50 years. Each wedge reduces emissions by 25 GtC over the time frame considered (Figure 2.1). The technology options proposed by

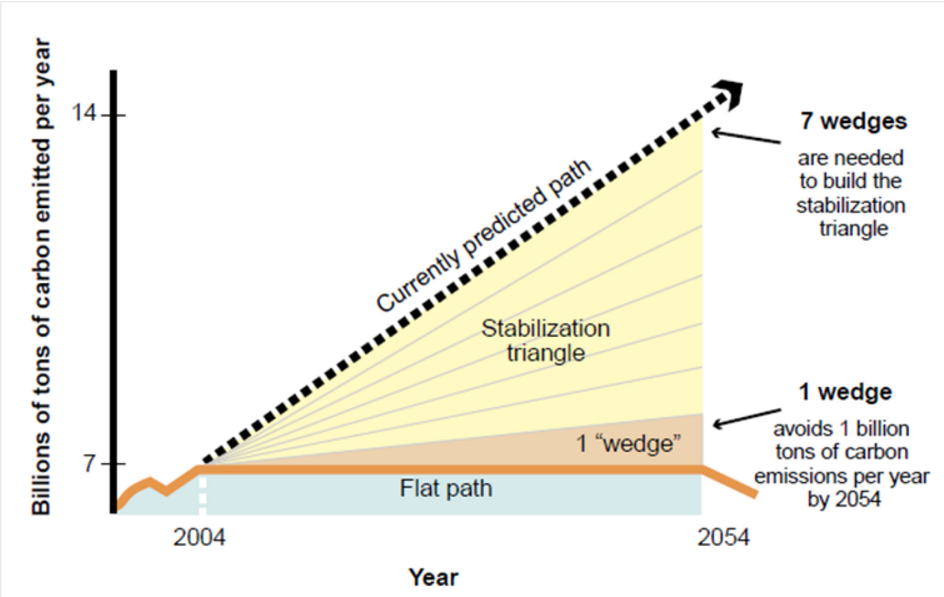
[3] The goal of the UN climate framework convention is '…to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.' In general the target value is assumed to be a concentration of at most about 500 ppm CO_2e, meaning a value below definitely the double of the pre-industrial concentration (280 ppm).

[4] This corresponds to the current global emissions of about 42 Gt CO_2 equivalent. Due to the growth in population and economic activity (especially in emerging countries) business as usual forecasts assume a doubling of this value until the middle of the 21st century (Nakicenovic, 2005, Stern, 2006).

Pacala and Socolow can be assigned to three categories, namely "energy efficiency and conservation", "decarbonisation of electricity and fuels" and "natural sinks". The technology options reflect alternatives from which one can choose, given the specific framework conditions in different countries. Not all technologies or measures will be appropriate or feasible for country specific circumstances.

Pacala and Socolow (2004) offer a highly operational approach for analysing induced technological change. For technologies used in energy generation that have an impact on CO_2 emissions, they propose a restructuring of the global energy sector based on currently known and available technologies that would hold the current level of carbon constant at seven billion tons per year (GtC/year) over the next five decades.

Figure 2.1: The technology wedges concept



Source: Hotinski et al. (2004).

Carbon emissions would double in the next 50 years if current trends are extrapolated. Keeping emissions constant would therefore require a technology shift that provided a total emissions reduction of 7 GtC/year by 2054. According to Figure 2.1, the "ramp" trajectory representing trend emissions and the "flat" trajectory representing constant emissions form a "stabilisation" triangle that is divided into seven technology "wedges", each of them representing a technological shift that cuts 1 GtC/year after five decades starting from zero today.

The projected emissions extrapolate the annual 1.5% carbon emissions growth over the past 30 years, which corresponded to a 2% growth in primary energy consumption and a 3% growth in economic activity as measured in gross world product. These figures indicate the historic decline in energy intensities and carbon intensities.

Altogether, a menu of 15 technology wedges is presented, each scaled up to an emission reduction of 1 GtC/year 50 years from now. Table 2.1 summarises the proposed technology wedges.

Table 2.1: Technology wedges for global GHG stabilisation

Category 1: **Efficiency and conservation**	Improved fuel economy	Increasing the fuel efficiency of cars
	Reduced reliance on cars	Reducing the annual distance travelled by cars
	More efficient buildings	Improving energy efficiency of residential and commercial buildings
	Improved power plant efficiency	Increasing fuel efficiency of power plants
Category 2: **Decarbonization of electricity and fuels**	Substituting natural gas for coal	Fuel shift in power plants
	Storage of carbon captured in power plants	Hydrogen for on-site electricity production
	Storage of carbon captured in hydrogen plants	Hydrogen for off-site use
	Storage of carbon captured in synfuel plants	Synthetic fuels from coal
	Nuclear fission	Doubling current instalments for one wedge
	Wind electricity	50 times today's deployment for one wedge
	Photovoltaic electricity	2 m2 per person for one wedge
	Renewable hydrogen	Hydrogen produced by windmills
	Biofuels	One-sixths of global croplands for one wedge
Category 3: **Natural sinks**	Forest management	Stopping clear-cutting of primary tropical forest, afforesting and reforesting
	Agricultural soils management	Conservation tillage practices

Source: Based on Pacala – Socolow (2004).

The time horizon of fifty years is chosen as on the one hand in this time span changes in energy provision and consumption and production patterns can be achieved and on the other hand it is decisions today that determine considerable parts of infrastructure and other capital stock over the next decades. Nevertheless as illustrated in Figure 2.1 further action is needed beyond 50 years in order to achieve a stabilisation of GHGs in the atmosphere. The wedges approach is appealing as it splits a huge endeavour into concrete manageable pieces. The focus on the deployment and scaling up of known technologies stresses the urgency of dealing with climate change that excludes the option of waiting until a revolutionary not yet known technology might be available in the future. It also highlights the contribution that can be achieved by existing technology options as well as the need for early research of follow-up technologies.

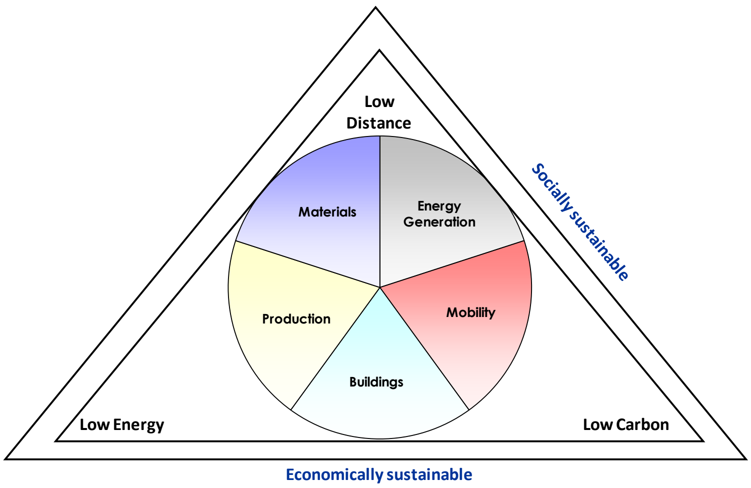
2.2 The extension of the Pacala-Socolow approach in the EnergyTransition project

The Pacala and Socolow paper focuses mainly on energy technologies and their impact on CO_2 emissions but the concept of technology wedges has a much broader relevance: It deals with the dynamics of a technology from its introduction up to a specific rate of implementation. It is a bottom-up analysis, and thus has the potential for revealing the detailed economic impacts of implementing a specific technology, both in the investment phase and in the operating phase.

The main contribution of Pacala and Socolow is a procedure for opening the black box of technologies. The project EnergyTransition takes the concept of technology wedges by Pacala and Socolow as a starting point and transforms and extends the concept with respect to technology options for Austria.

The overall principles for an energy strategy for Austria are depicted in Figure 2.2 and are described in Part A, chapter 1. The principles of sustainable development form the overall shell of the transformation process. These are to be achieved by the guidelines "low energy-low carbon-low distance" as described in Part A, chapter 1. The core then is the application of these two layers to the sectors mobility, buildings, production, and energy supply. The role of materials, with a focus on polymers, in certain application technologies is explicitly discussed.

Figure 2.2: Principles of sustainable development



Source: Own illustration.

One of the extensions of the concept of technology wedges in the project EnergyTransition concerns the focus on energy services. Three basic areas are identified for the analysis

- buildings,
- mobility, and
- production.

For these sectors desired energy services are defined (e.g. comfortable room temperature). Thus, the analysis of the energy system contrary to common approaches starts at the end of the system: the welfare generating energy services. From there the whole energy cascade (as described in Part A, chapter 1) is traced back to final energy demand and primary energy supply. Application and transformation technologies to meet the energy services determine final energy consumption and primary supply. Again the role of materials is an integral part for certain areas.

As in Pacala and Socolow (2004) technology wedges are then defined for the respective service needs. The focus on energy services extends the notion of technology options as used in the original technology wedges concept. In the project EnergyTransition e.g. behavioural changes as for example less kilometres driven are just as well a technology option in order to reduce energy demand and GHG emissions as e.g. electric vehicles. Thus the technology portfolio deviates from the definition of technology in a narrow sense. This also means one has to control for overlapping effects when technology wedges are combined.

A more fundamental extension refers to the economic assessment of the technology options. This delivers information on the costs of specific technology options for the investment phase on the one hand and the operating phase on the other hand.

3 Technological lock-in in energy systems

The fact that industrial economies and their fossil-fuel based production and consumption patterns are not sustainable and are the main contributors to climate change and other environmental externalities has become widely acknowledged. Energy generation and especially transport rely to a large extent on fossil fuels and cause a huge part of greenhouse gas emissions. In Austria currently (2008) energy industries (electricity and heat generation, refineries) account for 16% of greenhouse gas emissions. On average the share in the EU 27 is 31%. Due to the high share of hydropower electricity production in Austria is less carbon intensive than in the EU on average. Transport in Austria has a share of 34% in total final energy demand (32% in the EU 27) and of 26% in total greenhouse gas emissions (19% in the EU 27).

Unruh (2000) argues that industrial economies have become locked into fossil fuel based technological systems through a path-dependent process driven by technological and institutional increasing returns to scale (carbon lock-in).

Initially the carbon-based technologies emerged at a time when fossil fuels were abundant and concern as well as knowledge about long-term environmental impacts was limited. Innovation is usually characterised by uncertainty about future markets, the technology's further potential and development, potential future risks or negative externalities etc. Policy and investment decisions in relation to new technologies are made in the presence of these uncertainties and thus unintended side-effects like environmental damage can be locked-in along with the technology.

The interdependence of technological, institutional and social forces perpetuate the respective infrastructures despite their known environmental effects and create inertia[5] that impedes the large-scale deployment of alternative technologies.

The difficulties of a system change are not only to be found in the competitive advantages of carbon-based technologies in terms of cost, performance or applicability but also in a co-specialised network of technologies (infrastructure, end-use applications) and the interests of private and public institutions.

The role of technologies for reaching a path of sustainable development and mitigating climate change is highlighted in the scientific as well as political discourse. However, besides carbon-free or energy efficient technologies that are already available (e.g. renewable energy sources, combined heat and power production etc.) radical innovations that also involve a change in the technological system are called for in the longer term (see Geels et al., 2004). The following paragraphs will discuss the sources of technological lock-in with a focus on energy systems, the concept of the "techno-institutional complex" that creates systematic barriers to the adoption of alternative technologies as well as approaches supporting the development of radical innovations.

3.1 Lock-in of technological systems

Invention and innovation processes can result in the creation of various technological variants for meeting certain (expected) consumer demands. After a period of competition for performance improvements and market shares one technology will eventually become the standard or dominant design (Unruh, 2000). This does not necessarily have to be the superior technology or it can be related to negative environmental effects. Examples for this are for instance the QWERTY keyboard (David, 1985), light water nuclear reactors (Cowan, 1990), gasoline cars (Cowan – Hultén, 1996; Unruh, 2000) or pesticides in agriculture (Cowan – Gunby, 1996). Inferior alternatives can prevail or become locked-in as a result of timing, strategy or historic circumstances[6]. An initial advantage gained by one technological variant

[5] Systems that exhibit positive feedbacks through increasing returns to adoption are characterised by three features: path-dependence, inflexibility and potential regret (Cowan – Gunby, 1996).

[6] This includes political problems demanding immediate solution as well as chance events. Cowan – Hultén (1996) describe in detail the competition between electric, steam an gasoline cars and the events that contributed to the success of gasoline cars.

can result in rapid improvement of the technology (snowballing effect) and subsequently market domination due to the existence of increasing returns. Economic literature distinguishes four kinds of increasing returns (Foxon, 2007; Unruh, 2000):

1. Scale economies – unit production costs decline with increasing output,
2. Learning economies – product improvements or cost reductions as specialised skills and knowledge are accumulated,
3. Adaptive expectations[7] – increasing adoption reduces uncertainty regarding quality, performance or durability of a technology,
4. Network or co-ordination economies – the net benefit of using a technology rises with the degree of its adoption[8].

As technologies become locked-in there is a shift from product innovations to incremental improvements of the technology (technological trajectory). Firms invest in projects to reduce production costs and improve quality. Through the continuous specialisation the acquisition of knowledge is constrained as options that lie outside the dominant design and are not compatible with the system are not pursued[9]. Thus, radical innovations do rarely take place in firms that produce dominant design technologies and technological progress is shaped by the existing knowledge and proceeds in predictable directions (trajectories)[10].

In addition, technologies usually cannot only be seen as isolated physical artefacts but are part of broader networks including interdependent technologies or industries, infrastructures as well as institutional settings, and user relations (societal norms and customs)[11].

Regarding inter-industry network effects the automobile provides an illustrative example. The usefulness and attractiveness of the technology was not least determined by the simultaneous development of supporting industries, including component suppliers for the automotive industry as well as fuel production, service stations and the construction of the needed roadways. This created complex networks of co-specialised, interdependent and complementary assets (Unruh, 2000)[12]. Another relevant aspect in this regard is the need for

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[7] Cowan – Gunby (1996) and Cowan (1990) termed this "learning about payoffs".

[8] One example for network externalities is the telephone. The network's value increases with the number of people that can be contacted.

[9] Above the firm level the diffusion of new technologies can lead to the establishment of new academic disciplines for educating professionals and advance knowledge regarding the new technology. However, this can create large, self-sustaining networks of like-minded researchers, practitioners etc. that resist unorthodox ideas and advance the technology in path dependence.

[10] Rennings et al. (2009) examined the diffusion of incremental and radical innovations in the field of coal-fired power plants in Germany. Results show that radical innovations had difficulties being adopted and innovations are more likely to succeed when they follow established technological trajectories.

[11] Consumption also comprises the "cultural appropriation of technologies" as these have to be integrate in the users' practices, routines, organisations which involves learning and adjustments (Geels, 2004).

[12] The technological and economic linkages between industries have also been described in Dahmén's concept of the development block, which consists of a set of interrelated complementarities that connect firms from different industries into a network (Cowan – Hultén, 1996, Dahmén, 1989).

coordination and standardisation of such industry networks that takes the form of codified standards and conventions (legal standards, certifications like ISO norms etc.). These on the one hand reduce uncertainty about product/technology characteristics but on the other hand contribute to the institutional lock-in of central features of the dominant design.

As the use of a technology increases, i.e. the technological system grows, also user behaviour and social habits adapt. The integration of the automobile in daily life, for instance, had a significant influence on individual preferences, social routines and decisions concerning residence, work and leisure time activities, and the car was also used as a status symbol (Cowan – Hultén, 1996). Similarly, the co-evolution of electricity distribution networks and respective end-use technologies reshaped house work, leisure time etc. (Unruh, 2000). Thus, path dependence affects not only technological progress but also user expectations, preferences and strategies.

Another aspect that can exacerbate the lock-in effect from an interdependent technological system and widespread technology adoption (including changes in user behaviour and preferences) is government intervention. Policy in this respect can create "rules of the game" and thereby reduce uncertainty in the market about the direction of technological change. Such intervention can be either the definition of norms and standards, or take the form of subsidies or even government franchised monopolies or direct ownership. The interference in the development of technological systems can inter alia be justified on the following grounds (Unruh, 2000): national security[13], natural monopolies[14], universal service policies[15] or public safety[16]. As in the case of technological evolution according to the dominant design model institutions and policies once implemented tend to persist and behave risk aversely. As a failure of the technological system (e.g. through the introduction of radical innovations) would harm public welfare, threaten the objectives mentioned above and challenge the regulator's competence, there are incentives to support and perpetuate established technologies instead of risky alternatives.

Table 3.1 summarises some of the sources for technological lock-in that are the results of the co-evolutionary process of technologies, industries, institutions and societal routines described above.

[13] E.g. in the case of nuclear power (see Cowan, 1990).

[14] Public ownership of telephone or electricity networks.

[15] Extension of networks to ensure access for all citizens.

[16] E.g. through the definition of performance or safety standards.

Table 3.1: Sources of technological lock-in

Sources of Lock in	Examples
Technological	Dominant design, standard technological architectures and components, compatibility
Organisational	Routines, training, departmentalisation, customer-supplier relations
Industrial	Industry standards, technological inter relatedness, co-specialised assets
Societal	System socialisation, adaptadion of preferences and expectations
Institutional	Government policy intervention, legal frameworks, departments/ministries

Source: Unruh (2002).

3.2 Techno-institutional complex

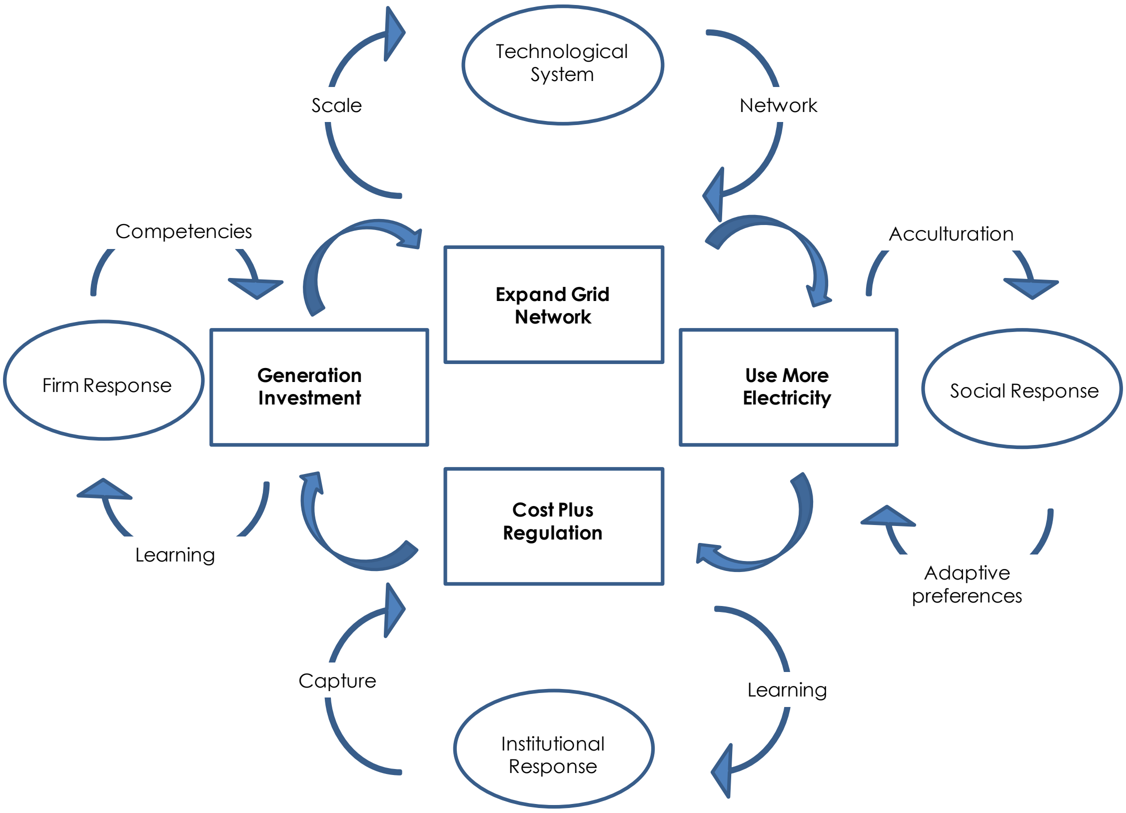
Closely interrelated technological systems and institutions that constitute a self-referential system at the macro-economic level are termed "Techno-Institutional Complex" (TIC) by Unruh (2000, 2002). TIC are the result of co-evolutionary processes, starting with technological increasing returns and maintained by public and private institutions that guide and manage the technology's diffusion and use. The inherent incentive structures affect the system's stability and evolution and obstruct the emergence of alternative technologies.

Carbon-based energy systems, like electricity generation, exhibit characteristics of TIC. Figure 3.1 illustrates some of the positive feedbacks that can be present in current electricity generation systems and govern their evolution in a simplified way (see Unruh, 2000).

The basic elements of this approach are the physical capital of the technological system (power plants, generation grid), private organisation and public institutions that operate and regulate the system and the larger societal framework in which it is embedded.

Starting from a point in which investment in new generation capacity is approved by the regulating authority, the expansion of the system and related learning effects with the new installations reduce generation costs and increase reliability. A decrease in prices and supply of new end-use technologies from secondary industries encourage a rise in electricity demand by consumers. This, in turn, could lead to a situation in which the existing capacity is fully utilised and investment in new capacity would become necessary to meet the growing demand.

Figure 3.1: Simplified illustration of the techno-institutional complex in electricity generation systems



Source: Unruh (2002).

Thus, the path-dependence of a technology is path-interdependent with economic, technical and political/societal decisions elsewhere in the economy (Cowan – Hulten, 1996). Once a technology has gained an advantage in the competition with its alternatives, it is the processes that occur in response or as reaction to technology diffusion that generate the vested interests that lock in the technology. Features that can cause lock-in (specifically mentioned by David (1985) regarding the QWERTY keyboard) are economies of scale, technical interrelatedness and quasi-irreversibility of investment. Technological trajectories are stabilised through many aspects: scale economies and sunk investments (machines, infrastructure, competencies, R&D), path dependent routines of engineers, regulations and standards, adaptation of lifestyles to technical systems (including investments of time and money) by users. The material networks and structures (especially relevant for infrastructure intensive technological systems like electricity generation) constitute particular inertia which make them difficult to change once they have been created. This aspect includes complementarities between components and sub-systems that depend upon each other for their functioning (Geels, 2004).

3.3 Escaping lock-in – innovation for a transition to more sustainable systems

The current carbon-based energy and transport systems produce large environmental externalities like emissions of greenhouse gases, other air pollutants, and noise and are dependent on non-renewable fossil energy sources. A change towards a more sustainable system should significantly reduce environmental damages while at the same time minimise social and economic disturbances. To this end three types of changes can be considered (see Unruh, 2002 and the literature cited therein):

In general the first approaches applied are end-of-pipe solutions that remove pollution after it has been produced, leaving the technological system and infrastructure unchanged. In case such add-on technologies are insufficient to remove the environmental externality or are technically or economically not feasible intra-system innovations are sought, that leave the major part of the system in place and focus on certain system components. These approaches can be regarded as incremental innovations or "continuity" approaches. The most disruptive option ("discontinuity" approach) would finally be the replacement of the existing system and the transition to an alternative, superior design consisting of radical innovations.

Regarding greenhouse gas emissions end-of-pipe solutions (e.g. biological sinks, carbon capture and storage) seem to be rather costly and it must be doubted whether they would deliver the massive reductions necessary to stabilise atmospheric GHG concentrations. Continuity approaches in this context would maintain the overall system architecture (e.g. the distribution grid, roadwork networks) and introduce changes in components in order to reduce emissions (e.g. raising the share of renewable energy sources in electricity generation, development of more fuel efficient engines, increase the use of hybrid or electric cars). Discontinuity approaches in comparison would focus on a substitution of large-scale centralised, fossil fuel based electricity and heat production by distributed generation based on renewable energy (in combination with highly efficient end-use technologies). Regarding transport systems a move towards integrated public transport systems and different development and settlement patterns (including life style changes) can be thought of as discontinuity approaches.

Which of the options described can be realised depends largely on the possibility to overcome technological and institutional lock-in and system inertia. Theoretical literature argues that "annealing forces" or major crises are required in order to create impetus for radical change (see Unruh, 2002 and the literature cited therein). Cowan – Hultén (1996) refer to six categories of extraordinary events that can constitute prerequisites for escaping lock-in[17]:

[17] Smith et al. (2005) argue that "without at least some form of internal or external pressure [...] it is unlikely that substantive change to the development trajectory will result." Pressure in this sense includes economic pressures (competition, taxes, regulations) as well as broad political, social or economic developments and pressures that are created by innovative niches.

1. Crisis in the existing technology (e.g. in a case where a technology fails to deliver the expected benefits[18]),
2. Regulation (e.g. banning the use of CFCs in refrigerators),
3. Technological break-through resulting in large cost decreases (e.g. as in the case of Ford's mass production of automobiles),
4. Changes in taste (e.g. through increased environmental awareness),
5. Niche markets (see below),
6. Scientific results (development pressure through knowledge about environmental effects or alternative technologies).

As described above, it is increasing returns (to adoption) that support the transition to new technologies. Increasing returns depend on a growing market share in order to be realised. Therefore, one challenge – besides the (radical) technological innovations – is creating a market, where alternative technologies can evolve. One possible strategy in this respect is nurturing technologies into increasing returns in specialised market niches (Unruh, 2002).

One framework that illustrates the interactions and linkages of elements in a wider technological system can be found in the work of Kemp (1998), Geels (2004)[19] and Geels – Schot (2007) on technological niches, socio-technical regimes and landscapes[20]. According to Rip – Kemp (1998) "A socio-technical regime is the rule-set or grammar embedded in a complex of engineering practices; production process technologies; product characteristics, skills, procedures; ways of handling relevant artefacts and persons; ways of defining problems; all of them embedded in institutions and infrastructures." This concept illustrates the interactions between actors and institutions that create and maintain a certain technological system or dominant design. Landscapes in turn can be thought of as the exogenous environment, i.e. broader political, social and cultural values and patterns, macro-economic developments. Higher levels in this approach are characterised by greater stability and resistance to change and thus guide the direction of change in lower levels (stabilising technological trajectories) and allows merely incremental innovation. Radical innovations in contrast are generated in niches[21], i.e. market spaces that are to a certain degree protected from market selection and that provide "incubation rooms" for radical ideas (Schot, 1998), learning processes and the constitution of networks. Thus, strategic niche management is put forward by the proponents of this approach (Kemp et al., 1998) as a method of supporting

[18] Cowan – Gunby (1996) describe this effect for pesticides in agriculture.

[19] For a summary see Foxon (2007).

[20] Technological niches and socio-technical regimes are similar kinds of structures (organisational fields, guided by regulative, normative and cognitive rules) but different in size and stability, while landscape is a different kind of structure providing deep-structural "gradients of force" that make some actions easier than others (Geels – Schot, 2007).

[21] As discussed by Unruh (2002) niches seem appropriate for the development of innovative system components, it may prove difficult to create niches for the change of an entire system like electricity generation.

radical change and transition to more sustainable systems. If the growth of niches is accompanied by changes on the regime level, then a transition to more sustainable regimes becomes possible (Geels, 2004). Transitions are thus generated by the interaction of processes on different levels (Geels –Schot, 2007):

- Niche-innovations create momentum through learning processes, performance improvements and interest group support,
- Changes at the landscape level create pressure on the regime,
- Destabilisation of the regime creates windows of opportunity for the niche-innovations.

Geels – Schot (2007) propose different transition pathways based on the relationship of niche-innovations, the technological regime and the superordinate institutional and social system (landscape). Three of these pathways can be compared to the concept of Unruh (2002) described above: Given a certain degree of landscape pressure on the technological regime technical variations in the system appear, new regimes grow out of old ones and even external knowledge may be imported if the distance with regime knowledge is not too large. In this "transformation pathway" the basic system architecture is not changed and radical innovations cannot take advantage because they are not sufficiently developed. If landscape pressure is large (disruptive change) and radical innovations are available there can be a window of opportunity for the replacement of the incumbent technology by the innovation (technological substitution pathway). If the radical innovations have symbiotic relations with the regime, they can be easily incorporated and used as add-ons or component replacement. The adopted novelties however may lead to further adjustments, technical changes and changes in user practices, perceptions etc. In combination with outside pressure such a sequence of innovations can lead to a major reconfiguration and regime changes (reconfiguration pathway).

However, the change in institutional priorities and the underlying change in social preferences (e.g. widespread recognition of environmental degradation) happens only gradually and usually takes more time than the development of new technologies. Although the social recognition of a problem is necessary for creating "landscape" pressure on technological regimes, it may not be a sufficient condition and an additional crisis or shock may be required to trigger institutional policy changes.

Established technological systems like electricity generation and transport are characterised by a lock-in in fossil fuel based technologies that generate massive environmental externalities like greenhouse gas emissions. In addition these systems represent a network of inter-related technologies (generation capacities, grid networks, end-use applications), institutions and social routines and patterns that are relatively inert.

In the discussion concerning the mitigation of climate change radical innovations or a system transition are frequently called for, as incremental improvements that are generated within the existing technological regime seem insufficient for delivering the substantial reduction in greenhouse gas emissions necessary.

However, as the literature confirms, in this context not only technologies and innovations have to be taken into account, but also the broader context, including the interactions of industries, the institutional and regulatory framework as well as societal norms and preferences. These factors all contribute to the stabilisation of systems and inhibit major changes. The temporal dimension is also relevant in this respect as changes on the social and institutional level usually take more time than technological developments and happen rather slowly and gradually. Regarding network- and investment intensive systems like electricity generation the longevity of assets also plays an important role and system changes may cause substantial sunk investments.

For a strategy of system change not only the availability of radical innovations is necessary, but also a clear vision of potential transition paths as well as institutional reorganisation in order to escape not only technological but also socio-economic lock-in. The possibility of future externalities by alternative systems or technologies has to be considered and regimes should be designed flexible, allowing for future evolution.

4 Materials and energy demand

While there is a strong interrelation between energy services and the selection of material technologies as described below, it is difficult to comprehensively investigate the role of materials in the broad range of technology wedges as proposed by Pacala and Socolow (2004) and discussed in previous sections. Hence, the assessment of material technologies in this study focuses on two fields of application and the related energy services, namely buildings and living and vehicles and mobility.

4.1 Energy services and the importance of materials

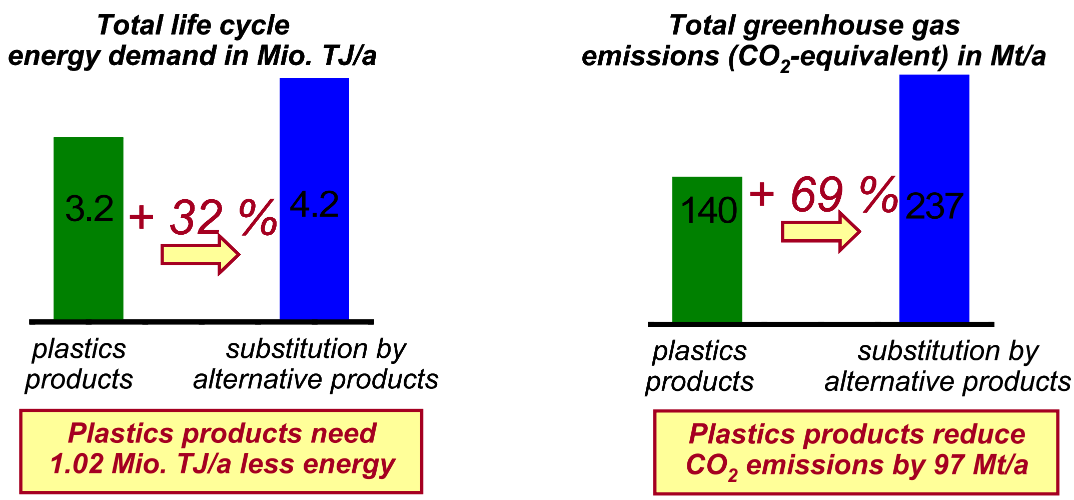
So far, only little attention has been paid to the effect of materials and material technologies on energy demand, energy supply and in particular energy services. But material technologies certainly play a key role in the energy system, especially in energy services related to buildings and living as well as vehicles and mobility. Thus it is quite obvious, that the selection of adequate materials and material technologies are of prime importance for the entire energy transformation chain. This is true for both, the field of energy efficiency (independent of the type of energy supply technology) and specifically also for energy supply technologies based on renewable resources. Independent of specific energy carriers and energy transformation technologies one must aim at the fulfilment of the required energy services in a high quality while simultaneously trying to achieve best or proper solutions in terms of technological simplicity and robustness as well as obtaining a high degree of freedom in design and keeping costs low.

Thus, when redesigning the energy system with a strong focus on energy services with appropriate transformation and application technologies materials and material technologies undoubtedly play a key role. Vice versa, the focus on energy services and the corresponding modifications and alterations in the application and transformation technologies will also affect the choice of the appropriate material technologies. Following the trends in other fields of technology, there are strong indications that polymeric materials (plastics, elastomers, composites, hybrid materials) will be a key motor for technological advances and innovations. In other words, compared to conventional classes of material such as metals, glass and ceramics, polymeric materials are expected to take an ever increasing role in the broad field of energy technologies.

4.2 Facts, data and status quo

The impact of material choice on resource efficiency in Western Europe has been investigated by Pilz et al. (2005) using a projection based method with a sufficient number of examples in a wide range of consumer and living standard relevant applications. Considering the total life cycle energy demand and the total greenhouse gas emissions in terms of CO_2e for such applications, plastics product solutions were compared with the next best alternative product solution based on metals, wood, paper, glass, etc. A main result of this study was that the plastics based product solutions need 32% less energy and reduce CO_2 emissions by 69% (see Figure 4.1). While this study provides clear evidence of the energy efficiency of existing plastics products in terms of their service performance, there is still a huge potential to improve these numbers by novel polymeric materials and by further product innovations.

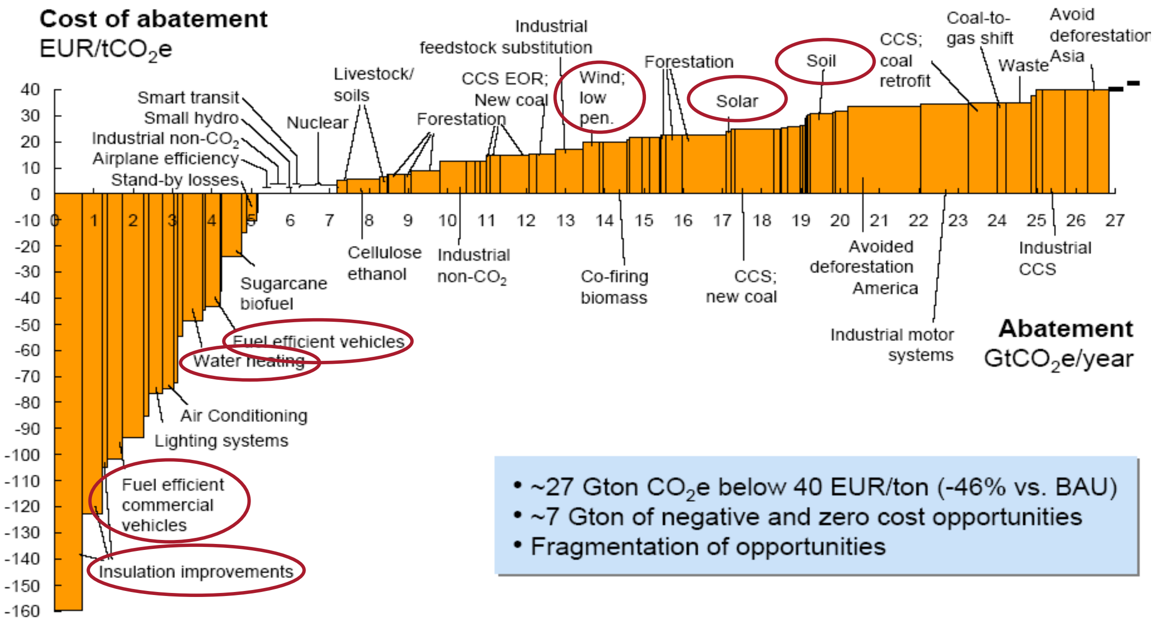
Figure 4.1: The contribution of plastics products to resource efficiency (total market of plastic products in Western Europe)



Source: Pilz et al. (2005).

Although indirectly, another interesting perspective on the role of materials was provided by a study of McKinsey – Vattenfall (2007). In this study a global CO_2 mitigation cost curve for 2030 was derived for a beyond business-as-usual scenario (see Figure 4.2). For this scenario the cost of CO_2 abatement is negative for ca. 7 Gt CO_2e and is below 40 €/t for up to 27 Gt CO_2e, which corresponds to -46% compared to the business-as-usual scenario. In terms of the analysed measures and corresponding technologies, most depend heavily on the use of plastics and other polymeric materials, the most prominent ones indicated by red ovals in Figure 4.2.

Figure 4.2: Global CO_2 mitigation cost curve for 2030 indicating the contributions of various measures and technologies



Source: McKinsey – Vattenfall (2007).

4.3 Challenges and relevant technology developments

In the following materials and material technologies are briefly discussed in the context of the two fields of applications, buildings and living and vehicles and mobility.

4.3.1 Buildings and living

With regard to the energy efficiency of buildings, material and component technologies for building construction elements and building infrastructure (thermal insulation, windows, fresh air supply and air exchange, etc.) have reached a rather high standard, so that primarily incentives and stimulations for a broad application and implementation are needed (e.g., passive house standard for new buildings and building renovation). Of course, although the quality standards of existing solutions have reached a high level, future development efforts are needed to further improve and optimise current technologies in terms of functionality, architectural building aesthetics, ease of construction and installation and cost.

In terms of renewable energy in particular solar energy technologies, there is a high potential for material-driven innovations in the field of solar thermal technologies (novel solar thermal collectors and collector systems with enhanced plastics use up to plug-and-function all-polymeric solutions) and solar electrical technologies (thin film photovoltaic modules of enhanced efficiency based on industrial processing technologies; wind turbines of different power categories, especially also small and ultra-small wind power generators in composite and hybrid material design).

4.3.2 Vehicles and mobility

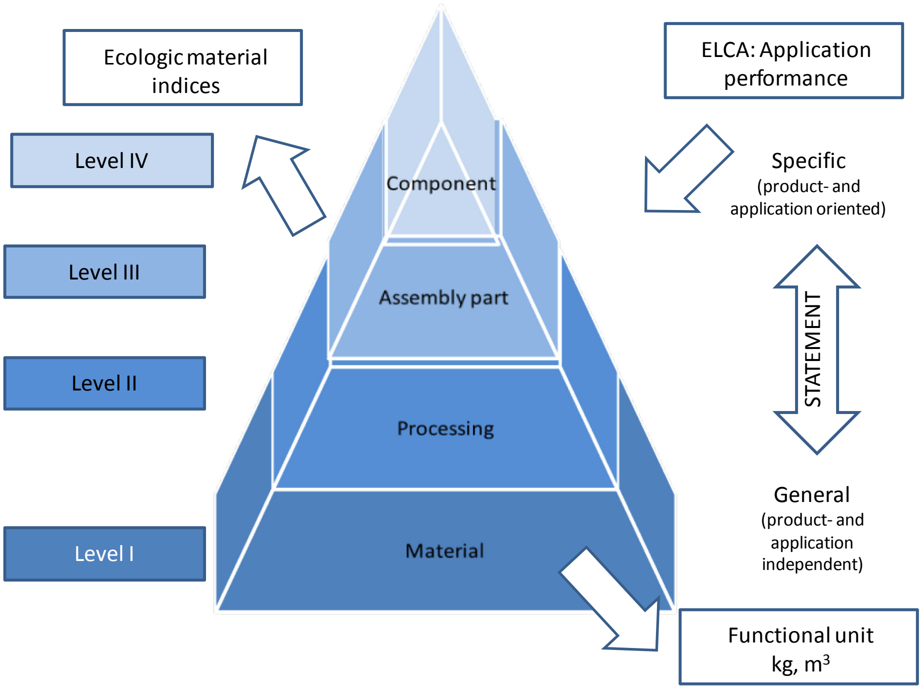
Energy efficiency in the field of mobility and of vehicles is primarily related to the total vehicle mass, to aspects of aerodynamics and outer shell vehicle design, to the rolling resistance of the tires and to the type and choice of the engine. Here too, materials and material technologies play a key role in all of these fields. As to the total vehicle mass, the aerodynamics and the rolling resistance, advanced light weight materials and structures based on composites and hybrid materials as well as the increasing use of high performance plastics and elastomers (e.g., for tires) are the main drivers of innovation. Along with the development of novel light-weight and ultralight-weight vehicle structures, the potential for significantly improved electrical engine systems with reduced requirements for the energy storage density also increases dramatically. However, a key element with regard to the use of electrical engine systems in vehicles is the energy supply via renewable technologies (water power, wind power, photovoltaics, etc.).

4.4 Definition and description of the modelling approach

The modelling approach assessing the energy efficiency of alternative material solutions was based on the principle of comparing the various solutions with regard to the same predefined performance level. The general approach of carrying out such an energy analysis is illustrated in Figure 4.3 in terms of an energy life cycle analysis pyramid which indicates the various levels of such an analysis. The first two levels cover the generic aspects related to materials and processes largely independent of a specific application, yielding numbers for the relative energy demand per unit mass (kg) or unit volume (m^3) of material. A comparison of the relative energy demand for various materials per kg of material is provided in Figure 4.4 including various types of polymeric materials and metals. Such a comparison, however, does not account for the difference in performance related properties of the various materials and thus does also not provide an indication on which material solution is to be preferred for a specific application. For example, the weight of plastics bottles usually is less than 1/5 the weight of a glass bottle. In other words, for such an application a comparison of the energy demand per kg material is certainly misleading.

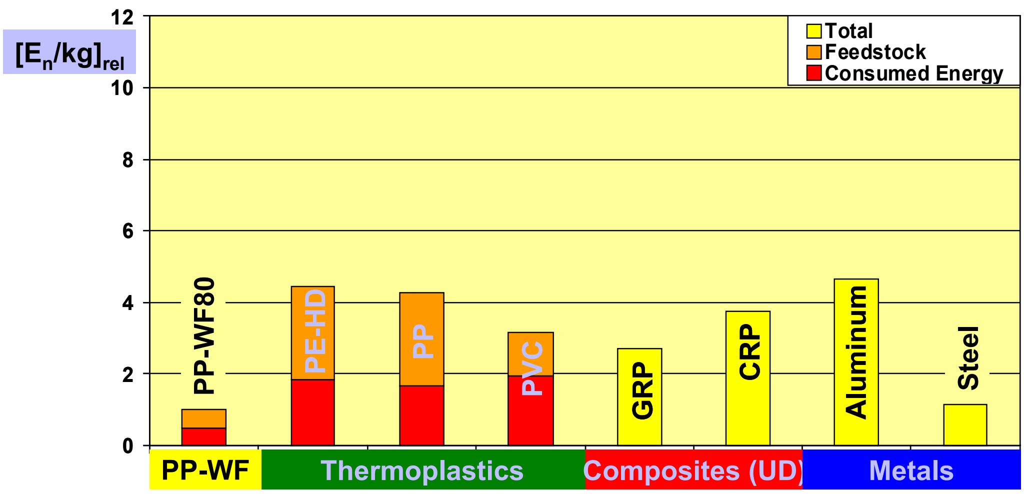
Hence, referring again to Figure 4.3, a meaningful energy balance or life cycle analysis must be carried out on the specific component or systems level using a predefined performance unit for the normalisation of energy demand figures.

Figure 4.3: Pyramid of energy life cycle analysis (ELCA) for various product and performance levels



Source: Svoboda (2003).

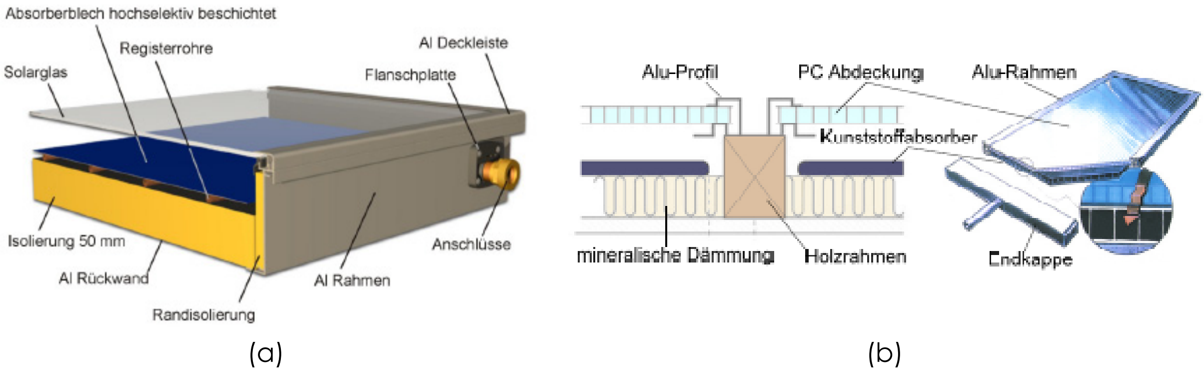
Figure 4.4: Comparison of the relative energy demand per kg material for various polymeric materials and metals



Source: Svoboda (2003).

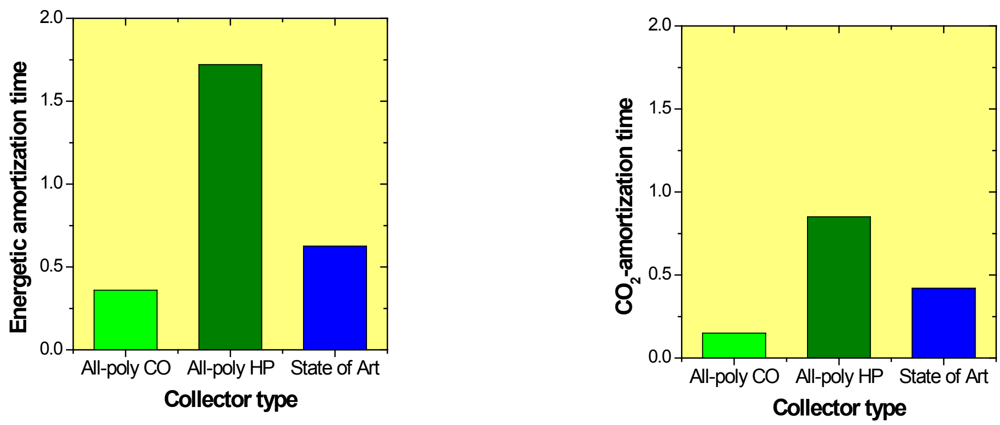
The approach outlined above was applied to solar thermal collectors of different design (see Figure 4.5) also using different material combinations in a study by Kicker (2009) as part of the present project. Major results of this study are shown in Figure 4.5 in terms of energetic amortisation time and CO_2-amortisation time, respectively. Compared are three collector types, including an existing standard commercial collector and two all-polymeric collectors with the same geometrical design (extruded panel and injection molded end caps), one using commodity type plastics, the other high-performance plastics (for the latter the collector design may be sub-optimal). This preliminary study highlights the potential of optimised polymeric solutions over existing collector systems.

Figure 4.5: Various collector types and designs; (a) state of the art solar thermal collector, (b) all-polymeric collector



Source: Kicker (2009).

Figure 4.6: Comparison of various collector types in terms of energetic amortisation time and CO_2-amortisation time



Source: Kicker (2009). All-poly CO = all-polymeric collector made of commodity plastics, All-poly HP = all-polymeric collector made of high performance plastics, state of art = state of the art collector.

The above outlined procedure on the impact of various material solutions on the energy and CO_2 balance are of crucial importance for solar electric components (PV modules), wind turbines and perhaps light-weight electrical vehicles.

Rather than looking at specific energy wedges for reasons indicated above, the issue of limited fossil fuel availability and the consequences from an increasing fossil fuel demand for the production of plastics and polymer products plays an important role. Thus various market growth scenarios for plastics merged with peak oil concepts need to be analysed in more detail and are addressed in Part B, chapter 10. In this context, prominent representatives of large oil production companies such as His Excellency Yousef Omair Bin Yousef have recently stated, that the future of oil usage should be in the production of high value products rather than in the one-step energetic use (OÖN, 2009).

Part B

1 Restructuring the Austrian energy system

1.1 A technology wedges approach for Austria

A number of targets from energy and climate policy require a fundamental restructuring of the Austrian energy system. These targets refer to the end of the Kyoto commitment period by 2012, to the ambitious EU 2020 targets and to the emerging goals for 2050 in the UNFCCC process.

EnergyTransition aims at identifying options that allow such a restructuring of the energy system (see Part A, chapter 1). Based on an analysis of energy services and technology choices, potentials for CO_2 emission reductions are examined.

The methodological approach is based on the concept of stabilisation wedges by Pacala and Socolow (2004). The stabilisation wedge approach highlights the role of technologies in reducing greenhouse gas emissions. Pacala and Socolow identify fifteen technology options (so called stabilisation wedges) based on already available technologies that allow a stabilisation of global greenhouse gas emissions in the next 50 years. Each wedge has the potential of cutting global CO_2 emissions by one gigatonne by 2054. Out of the menu of fifteen technology options, seven wedges have to be combined to achieve a stabilisation of greenhouse gas emissions (see Part A, chapter 2).

Within the project EnergyTransition the concept of technology wedges is for the first time applied to the Austrian energy system. Each technology wedge represents an option to lower Austrian CO_2 emissions by a certain amount until 2020. The basic concept of stabilisation wedges is extended in three ways:

- The technologies are embedded into an integrated structural model of the Austrian energy system that starts from energy services and ends with primary energy flows. The quantity of energy flows depends on the application and transformation technologies implemented.
- The characteristics of all technologies are described in a unified framework. The description includes economic parameters such as investment and operating costs as well as energy relevant parameters.
- Economic impacts from the implementation of different technologies are analysed for the investment and costs in the operating phase are depicted.

The following section contains a brief description of the structural model as a central element in extending the technology wedges approach.

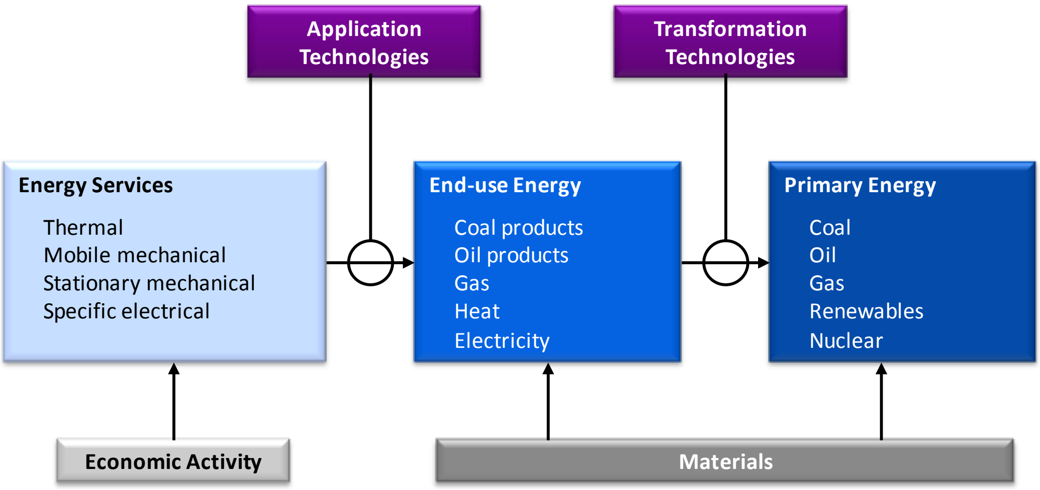
1.2 The structural model

Energy services and functionalities are the starting point for the structural model of the energy system. For buildings, mobility and industry the relevant energy services are analysed and a broad range of application technologies is described. Final energy consumption related to the energy services is identified based on the application technologies chosen. Energy supply is determined by final energy consumption, implemented transformation technologies and the fuel mix.

The substitution of energy by materials is another key element of the modelling approach. Substituting materials that are currently used by innovative materials – such as polymers – opens potentials for reducing energy flows and emissions. This applies both to application and transformation technologies. Light-weight vehicles, for example, allow a substantial reduction in fuel consumption in the transport sector; implementing polymers for photovoltaic and solar panels opens up a broad range of application possibilities.

Figure 1.1 summarises this integrated modelling approach ranging from energy services to primary energy supply. Economic parameters such as capital, economic activity and energy prices drive the demand for energy services. Application and transformation technologies determine final energy consumption and primary energy supply related to the energy services.

Figure 1.1: A structural model of the energy system



Source: Own illustration.

Outputs of the energy model such as energy flows or energy related investments serve as an input for an input-output-analysis in order to determine output and employment effects following the implementation of the technology wedges. Changes in energy flows show in the development of operating costs.

The two model components of the energy system – the demand module and the supply module – are described in the following section.

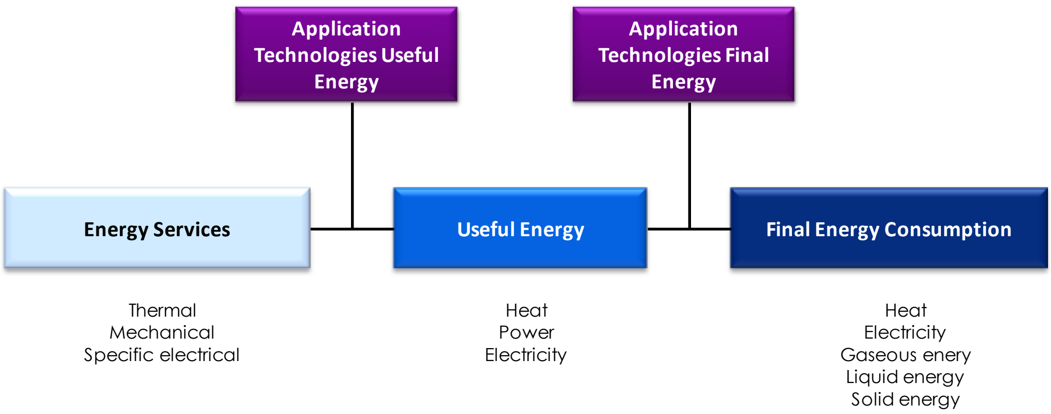
The demand module

Energy services – and not energy flows related to them – contribute to individual welfare. Therefore the demand module starts with an analysis of relevant energy services for the sectors buildings, mobility and industry. For these sectors the most relevant energy services are:

- thermal energy services (on different temperature levels),
- mechanical energy services (for stationary and mobile engines), and
- specific electric energy services (for lighting and electronics).

In order to provide an energy service a certain amount of useful energy is required which depends on the technologies implemented. Therefore, in a second step application and transformation technologies at the demand side are analysed. Based on the underlying energy services and the technologies used to provide them final energy consumption is estimated (see Figure 1.2).

Figure 1.2: The energy demand module

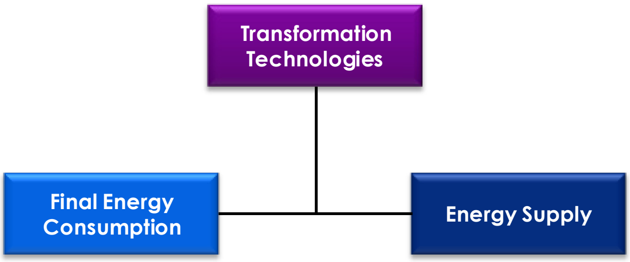


Source: Own illustration.

The supply module

The second model component describes the transformation of primary energy into final energy (see Figure 1.3). Both the quality (exergy) and the quantity of energy supply shall be in line with final energy demand identified in the first model component.

Figure 1.3: The energy supply module



Source: Own illustration.

Two technology choices for energy supply are highlighted in our modelling approach:

- the mix of primary energy supply (in particular the role of renewable energy sources), and
- the efficiency of transformation and distribution technologies in heat and electricity generation.

Economic aspects

Besides the detailed analyses of the energy system, starting from energy services, EnergyTransition aims at analysing economic effects of the investment phase until 2020 based on an input-output analysis. Data on investment costs are compiled from studies as well as information from stakeholders. With these data the macroeconomic output and employment effects for an average year can be calculated. Furthermore impacts of the operating phase for the considered technology wedges are discussed.

For a sample of technologies a microeconomic cost appraisal complements the results of the input output calculations.

1.3 Database

Data on energy flows is from the energy balances and balances of useful energy from Statistics Austria (Statistics Austria 2009a, b).

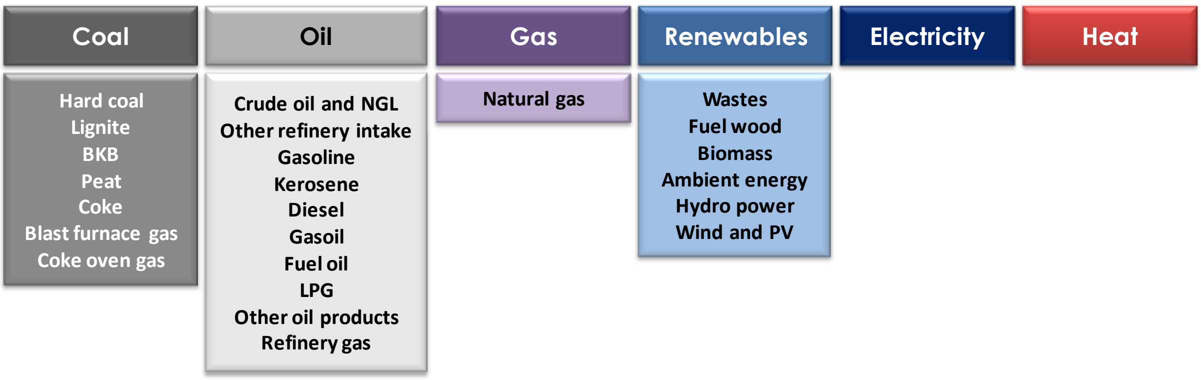
The energy balances compiled by Statistics Austria are summary tables of energy supply and consumption by fuel type and sector and cover the period 1970 to 2008. The energy balances have the following structure: they start from production of primary fuels and result in final energy consumption:

Supply			Consumption
	National production of primary fuels		Primary energy supply
+	Imports	-	Transformation input
+/-	Stock changes	+	Transformation output
-	Exports	-	Consumption of energy industries
=	Primary energy supply	-	Non-energy use
		=	Final energy consumption

The transformation process is divided into six transformation categories (coke ovens, blast furnaces, refineries, power plants, CHP plants, heat plants and gas production); for energy generation plants an additional distinction between energy supply companies and autoproducers is available.

By 2008, energy balance tables are available for 26 different fuel types (see Figure 1.4).

Figure 1.4: Fuel types in Austrian energy balance tables



Source: Own illustration.

In addition to the disaggregation by fuel type, final energy consumption is also disaggregated by sector. This sectoral disaggregation follows the classification used in the energy statistics by the International Energy Agency (IEA) and Eurostat. The energy balances distinguish between industry, transport, households, commercial and public services and agriculture. The industry sector is split up into 13 sub-sectors; the transport sector includes five sub-sectors.[1]

For our analysis of the Austrian energy system, we use energy balance data on final energy consumption and primary energy supply for the period 1980 to 2008. In addition, transformation input and output data are used for the calculation of the CO_2 emissions of the energy industries.

[1] The transport sector comprises all transport activities except those of agricultural vehicles. Motorised individual transport is included in the transport sector and not in the household sector.

Data on sectoral final energy consumption are supplemented by data from the balance of useful energy which provides information on the use categories of final energy consumption. The balance of useful energy distinguishes between seven categories of use:

- Space heating and air condition
- Steam production
- Industrial furnaces
- Stationary engines
- Traction
- Lighting and computing
- Electrochemical purposes

A detailed data compilation provided by Statistics Austria (2009b) for the project EnergyTransition allows the differentiation of final energy consumption by use category, sector and fuel type.

2 A reference scenario for the Austrian energy system

2.1 Modelling approach

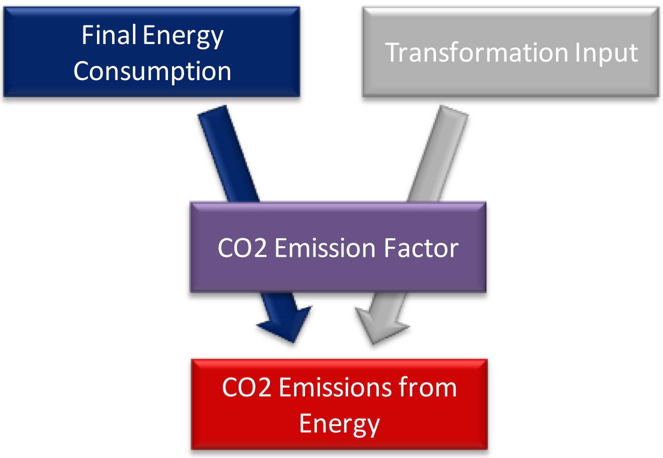
As a starting point for modelling the transition to a sustainable energy system that is in line with the energy and climate targets for Austria a reference scenario for greenhouse gas emissions is developed. The reference scenario represents the upper boundary of the reduction triangle from which emission reductions related to different portfolios of technology wedges are subtracted. This reference scenario for 2020 reflects an extrapolation of historical trends in energy flows and emissions[2].

The reference scenario covers three categories of greenhouse gas emissions:

- CO_2 emissions from final energy consumption and power generation,
- other CO_2 emissions, and
- other greenhouse gas emissions.

For the first category of emissions, the reference scenario is based on a projection of energy flows and consists of two scenario components (see Figure 2.1). The first component extrapolates CO_2 emissions related to final energy consumption (demand component). The second component (supply component) builds on final energy demand and extrapolates transformation input in energy generation plants and related CO_2 emissions.

Figure 2.1: The reference scenario for energy-related CO_2 emissions



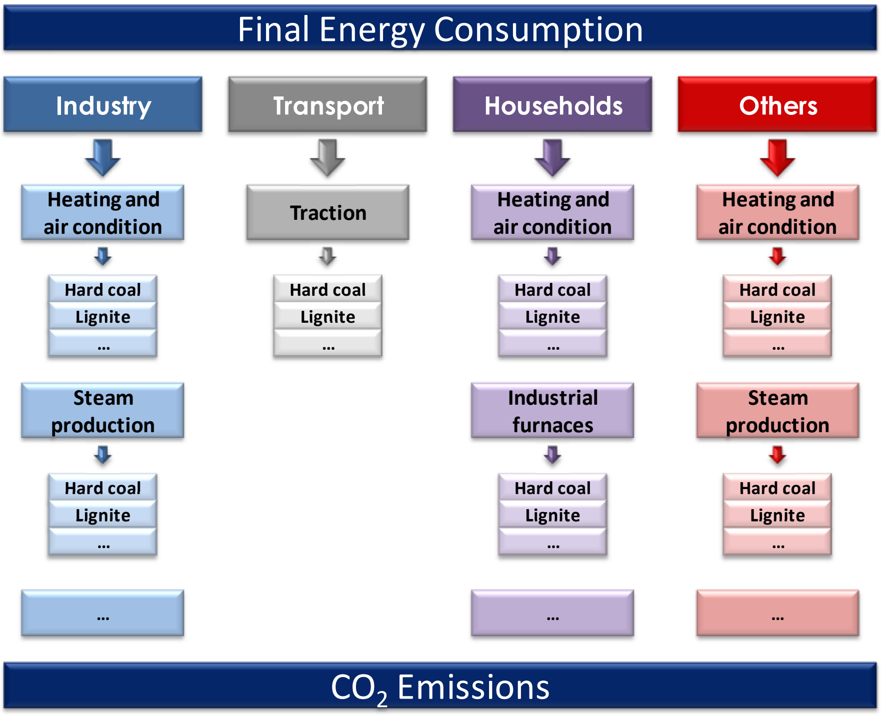
Source: Own illustration.

[2] The reference scenario represents a possible path for energy demand and emissions along past developments. It does not explicitly depict energy services as analysed in detail in the technology options for the areas buildings, mobility and industry.

2.1.1 CO_2 emissions from final energy consumption

Figure 2.2 illustrates the approach used for estimating CO_2 emissions from final energy consumption.

Figure 2.2: Projection methodology for CO_2 emissions from final energy consumption



Source: Own illustration.

The reference scenario is estimated in a sectoral approach. GDP elasticities of sectoral final energy consumption are used for the sectors transport, households as well "other sectors". For extrapolating final energy consumption of the household sector, historical energy consumption is additionally adjusted for variations in temperature. Final energy consumption is extrapolated until 2020:

(2.1) $F_i = f(Y)$

F_i Final energy consumption of sector i

Y Gross domestic product (GDP)

For the 13 manufacturing sub-sectors final energy consumption elasticities based on production indices are used for extrapolating sectoral final energy consumption:

(2.2) $F_i = f(PI)$

PI Production Index

GDP projections are based on WIFO's mid-term forecasts of the Austrian economy from January 2010. The WIFO mid-term forecast covers the period 2010 to 2014; past 2014 an annual GDP growth rate of 2% is assumed. For the annual changes in the production indices constant long-run averages are used.

In a next step, sectoral final energy consumption is disaggregated by use category. Sectoral final energy consumption in the different use categories adds up to total final energy consumption of the sector. The different categories of useful energy can therefore be projected by extrapolating the historical development of their shares in sectoral final energy consumption. Estimated shares are then multiplied with projected energy consumption.

(2.3) $F_i = \sum_j FU_{j,i}$

$FU_{j,i}$ Final energy consumption in use category j in sector i

(2.4) $FU_{j,i} = SU_{j,i} * F_i$

$SU_{j,i}$ Share of final energy consumption in use category j in sector i

Finally, final energy consumption in the different use categories is split up by energy source. The sum of different fuel types for every energy use category equals final energy consumption. Final energy consumption by energy source is projected by extrapolating the historical trends of the energy mix. The shares are again multiplied with energy consumption in the respective use category.

(2.5) $FU_{j,i} = \sum_j FE_{k,j,i}$

$FE_{k,j,i}$ Consumption of fuel k in use category j in sector i

(2.6) $FE_{k,j,i} = SE_{k,j,i} * FU_{j,i}$

$SE_{k,j,i}$ Share of final energy consumption in use category j in sector i

Total final energy demand is the result of the sectoral projections:

(2.7) $F = \sum_i F_i$

F Total final energy consumption

(2.8) $FU_j = \sum_i FU_{j,i}$

FU_j Total final consumption in use category j

(2.9) $FE_k = \sum_i FE_{k,j,i}$

FE_k Total final consumption of fuel k

CO_2 emissions related to final energy consumption are calculated by multiplying final energy consumption by fuel type with the corresponding emissions factors[3].

2.1.2 CO_2 emissions from energy generation

Transformation input of fossil fuels is projected starting from final energy consumption determined in the previous section. In a first step, final consumption of heat and electricity from fossil fuels as well as distribution losses in fossil power generation and consumption of energy industries are extrapolated (equation (2.10)).

(2.10) $TO_F = F_{el,F} + F_{h,F} + LD_F$

TO_F Transformation output from fossil energy generation

$F_{el,F}$ Final electricity consumption from fossil fuels

$F_{h,F}$ Final heat consumption from fossil fuels

LD_F Distribution losses and consumption in fossil energy generation

In a second step, transformation losses from heat and electricity generation from fossil fuels are extrapolated. Adding these losses to projected transformation output yields transformation input of fossil fuels (equation (2.11)).

(2.11) $TI_F = TO_F + LT_F$

TI_F Transformation input in fossil energy generation

LT_F Transformation losses in fossil energy generation

Finally, CO_2 emissions from heat and electricity generation are calculated by multiplying transformation input of fossil fuels in power generation plants with the corresponding CO_2 emission factors.

[3] We use emission factors from the UNFCCC National Inventory Reports (UNFCCC, 2010).

2.1.3 CO_2 emissions from other sources and emissions of other greenhouse gases

In 2008, CO_2 emissions from electricity and heat generation and CO_2 emissions related to final energy consumption accounted for 84% of CO_2 emissions and for 73% of total greenhouse gas emissions in Austria. Technology wedges will therefore only be developed for these emission categories. Other greenhouse gas emissions are, however, included in the reference scenario in order to estimate the overall emission reduction requirement.

CO_2 emissions from other sources – mainly process-related emissions – are not directly related to energy flows. Therefore, these CO_2 emissions are projected by extrapolating historical greenhouse gas emission data from the UNFCCC inventory submissions using GDP elasticities.

The same methodology is applied to other greenhouse gas emissions. These include

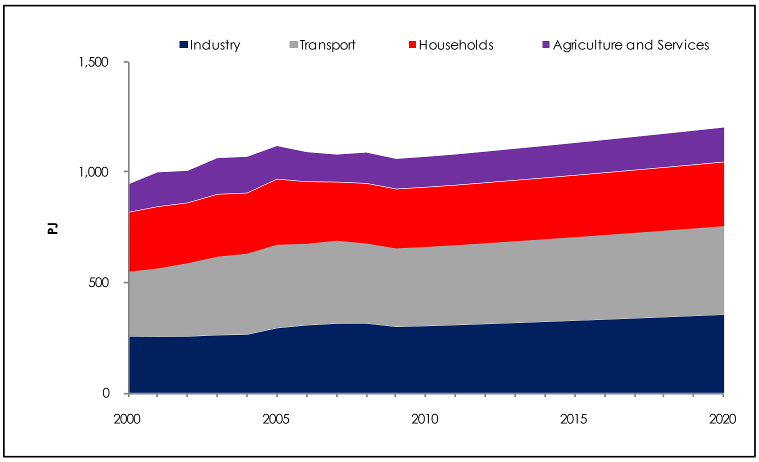
- methane (CH_4),
- nitrous oxide (N_2O),
- hydrofluorocarbons (HFCs),
- perfluorocarbons (PFCs), and
- sulfur hexafluoride (SF_6).

2.2 A reference scenario for energy consumption and emissions

2.2.1 CO_2 emissions from final energy consumption

In 2008 Austrian final energy consumption totalled 1,089 PJ. In the reference scenario final energy consumption is estimated to rise by 10% to 1,202 PJ by 2020. Figure 2.3 shows historical and projected final energy consumption by sector for the period 2008 to 2020. The transport sector accounted for 34% of total energy consumption (367 PJ) in 2008. By 2020 final energy consumption in this sector is estimated to rise by 11% to 406 PJ. In 2008, final energy consumption was second highest in the industry sector (312 PJ). For this sector the highest increase (13%) is expected by 2020. The household sector accounted for 25% of total final energy consumption in 2008; the share of the other sectors was 13%. For these sectors, final energy consumption is expected to grow by 7% and 12% respectively by 2020.

Figure 2.3: Reference scenario for final energy consumption by sector



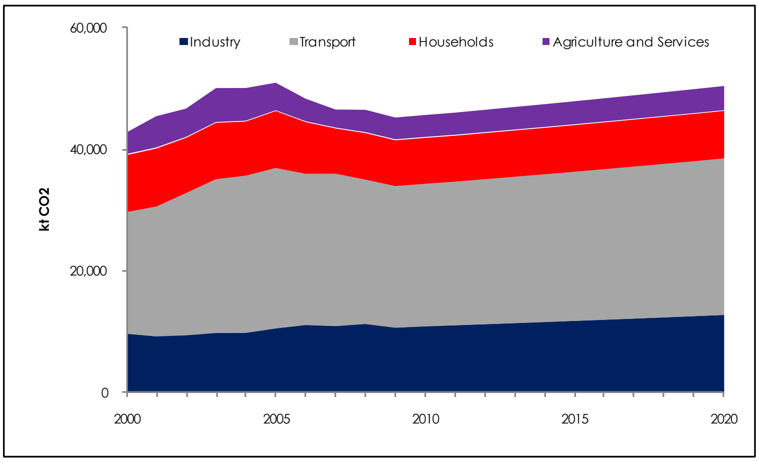
Source: Statistics Austria (2009a, b); own calculations.

CO_2 emissions from final energy consumption were 47 Mt in 2008[4]. For the reference scenario emissions are expected to rise by 9% to 50 Mt in 2020 (see Figure 2.4). The modest decoupling between growth of final energy consumption and growth of related CO_2 emissions is due to changes in the fuel mix (see below). The share of emissions from the transport sector is even higher than the sector's share in final energy consumption; in 2008 CO_2 emissions from transport accounted for more than 51% of emissions from final energy consumption (24 Mt) and are expected to rise to 28 Mt by 2020[5]. High emissions in the transport sector are due to a low share of electricity and renewables consumption in this sector. For the same reason, the emission shares of the household sector and the other sectors are lower than their shares in final energy consumption. In 2008 CO_2 emissions from households accounted for 8 Mt (16% of CO_2 emissions from final energy consumption); emissions from the other sectors were 4 Mt (6%). Both CO_2 emissions from the household sector and emissions from the other sectors are projected to slightly increase by 2020.

[4] CO_2 emissions from final energy consumption account for 62% of total Austrian CO_2 emissions; energy related CO_2 emissions account for 84% (own calculations based on Statistics Austria 2009a, b and UNFCCC, 2010).

[5] Emissions from air transport are not included as CO_2 emissions from international aviation cannot be assigned on country level.

Figure 2.4: Reference scenario for CO_2 emissions from final energy consumption by sector

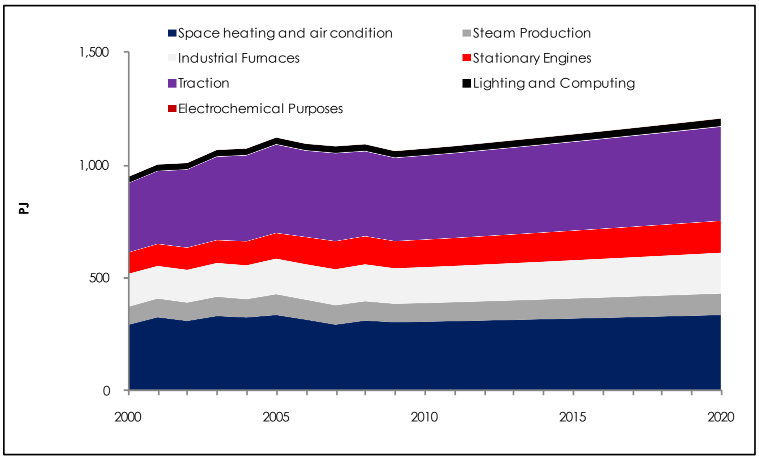


Source: Statistics Austria (2009a, b); own calculations.

Figure 2.5 shows the development of final energy consumption by category of use. Final energy consumption is highest in the use category traction which corresponds to the high energy consumption in the transport sector[6]. In 2008 final energy consumption for traction was 376 PJ; by 2020 a rise to 417 PJ is estimated. The second largest category is space heating and air condition. The household sector and the other sectors are responsible for 87% of final energy consumption in this category. For final energy consumption for space heating and air condition a rise of 8% from 314 PJ in 2008 to 339 PJ by 2020 is estimated for the reference scenario. Final energy consumption for industrial furnaces accounted for 160 PJ (15%) in 2008 and is expected to increase by 11% to 177 PJ by 2020. In 2008 11% of Austrian final energy consumption (123 PJ) accrued to the use category stationary engines; until 2020 final energy consumption in this use category is estimated to rise to 141 PJ. Steam production accounted for 8% of final energy consumption (85 PJ) in 2008. By 2020, final energy consumption is estimated to rise by 11% for this use category. For energy consumption in the use categories lighting and computing and electrochemical purposes high growth rates are projected; still the shares of these categories in total consumption are negligible.

[6] 97% of final energy consumption in the use category traction accrue to the transport sector; the remaining 3% accrue to agricultural vehicles.

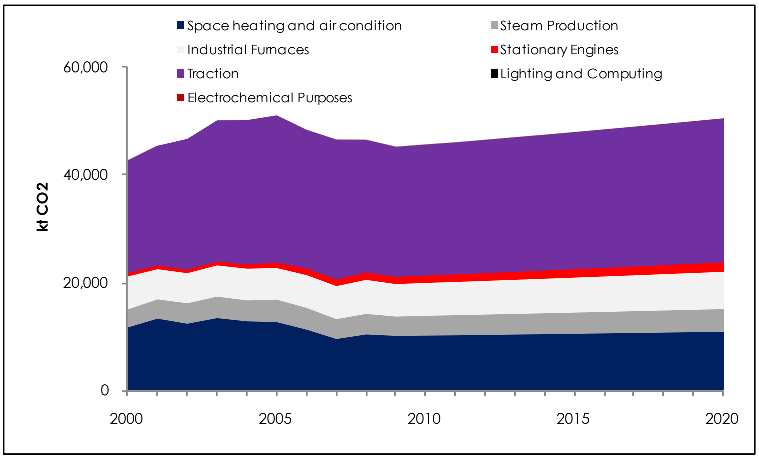
Figure 2.5: Reference scenario for final energy consumption by use category



Source: Statistics Austria (2009a, b); own calculations.

Figure 2.6 depicts the development of CO_2 emissions by category of final energy use. For the categories lighting and computing and electrochemical purposes, there are no emissions from final energy consumption, because for these categories only electricity is used. In 2008 the category traction accounted for 24 Mt CO_2 emissions (52% of CO_2 emissions from final energy consumption); CO_2 emissions from this category are estimated to rise to 27 Mt by 2020.

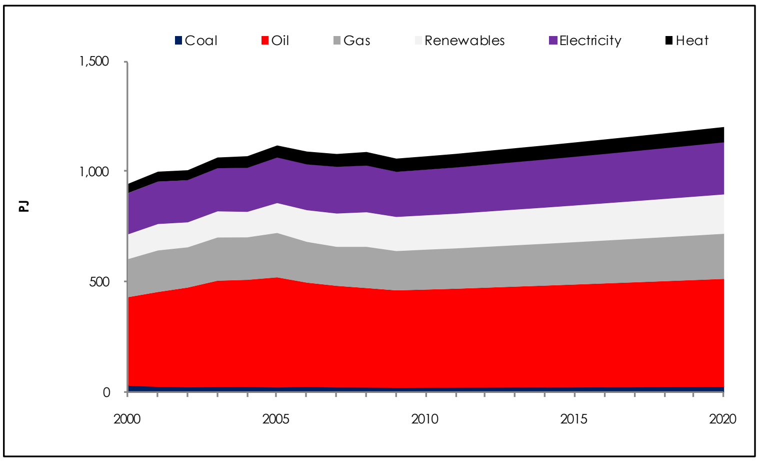
Figure 2.6: Reference scenario for CO_2 emissions from final energy consumption by use category



Source: Statistics Austria (2009a, b); own calculations.

Figure 2.7 shows the development of final energy consumption by fuel type. Consumption of oil products accounted for 41% of final energy consumption (448 PJ) in 2008 and is projected to grow by 9% by 2020. Electricity consumption was 211 PJ (19%) in 2008; for the reference scenario an increase of 12% by 2020 is estimated. Final energy consumption of gas accounted for 17% (189 PJ) in 2008 and is expected to increase by 9% by 2020. For final energy consumption from renewables an increase of 14% to 176 PJ in 2020 compared to 154 PJ in 2008 is projected. Final energy consumption of heat and coal was 62 PJ and respectively 24 PJ in 2008; for these fuel types increases of 12% and 10% respectively are estimated until 2020.

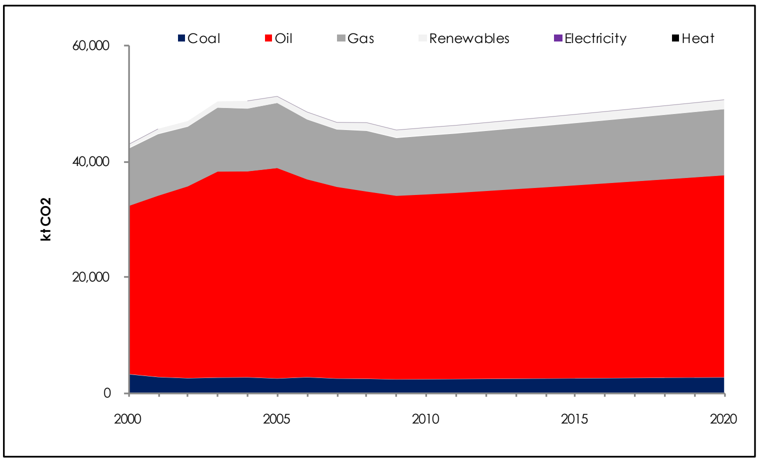
Figure 2.7: Reference scenario for final energy consumption by fuel type



Source: Statistics Austria (2009a, b); own calculations.

Figure 2.8 shows the development of CO_2 emissions from final energy consumption by fuel type. Emissions related to the production of electricity and district heating are combined in the emission balances as emissions from energy industries. With respect to renewables except for waste an emission factor of 0 is used. Due to the high emission factors of coal products, the share of CO_2 emissions from the consumption of coal is twice the share of coal in final energy consumption. CO_2 emissions from oil products accounted for 33 Mt (70%) in 2008; by 2020 a rise to 35 Mt is estimated for the reference scenario. CO_2 emissions from gas consumption were 10 Mt in 2008 and are estimated to increase only modestly by 2020.

Figure 2.8: Reference scenario for CO_2 emissions from final energy consumption by fuel type

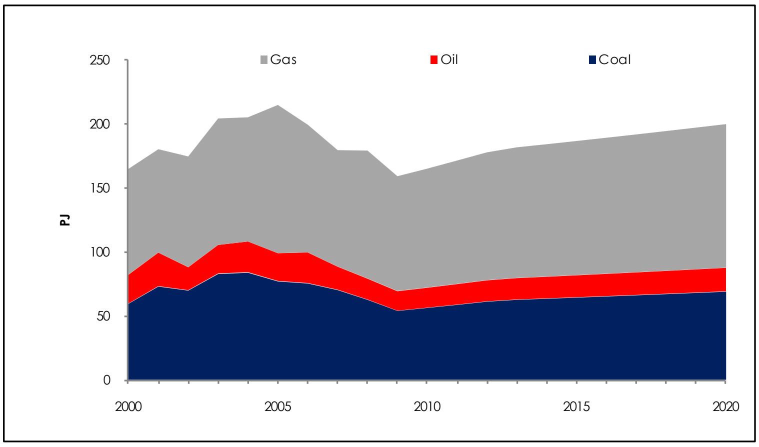


Source: Statistics Austria (2009a, b); own calculations.

2.2.2 CO_2 emissions from electricity and heat generation

Calculations of CO_2 emissions from electricity and heat generation are based on the transformation input of fossil fuels in energy generation plants. Figure 2.9 shows the development of fossil transformation input of energy production companies and autoproducers by fuel type. In 2008 transformation input of fossil fuels was 180 PJ; it is estimated to rise by 12% to 200 PJ by 2020. Gas is the most used fossil fuel in the transformation process (56%) in 2008, followed by coal (35%) and oil (9%). Energy generation from all fuel types is expected to increase until 2020.

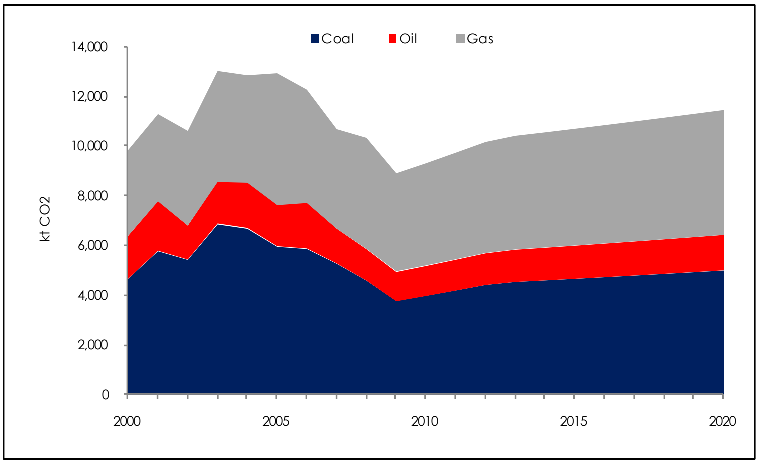
Figure 2.9: Reference scenario for transformation input of fossil fuels



Source: Statistics Austria (2009a, b); own calculations.

CO_2 emissions from electricity and heat generation were 13 Mt in 2008 and are projected to increase by 11% to 14 Mt by 2020 (Figure 2.10). CO_2 emissions from coal based electricity and heat generation exceed emissions from gas. This is due to the higher emission factors of coal products.

Figure 2.10: Reference scenario for CO_2 emissions from heat and electricity generation by energy source



Source: Statistics Austria (2009a, b); own calculations.

2.2.3 CO_2 emissions from other sources and other greenhouse gas emissions

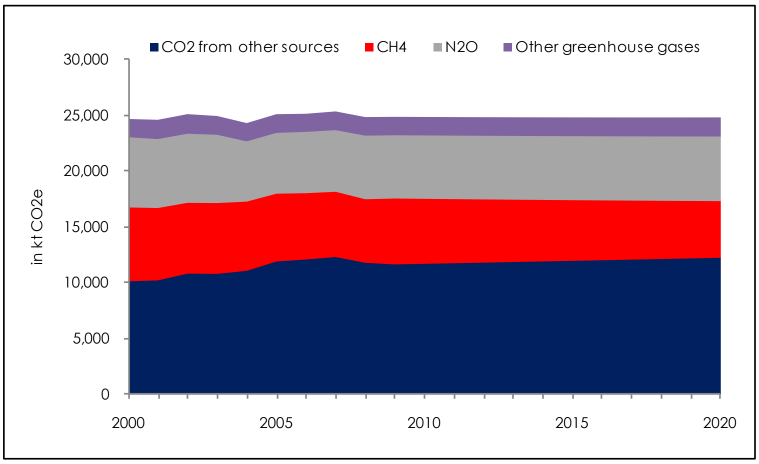
Figure 2.11 shows the development of other greenhouse gas emissions. In 2008, CO_2 emissions from other sources and emissions of other greenhouse gases accounted for 27% of Austrian greenhouse gas emissions (25 Mt CO_2e). By 2020 this share is expected to slightly decrease.

CO_2 emissions from other sources accounted for 48% of the remaining greenhouse gases in 2008 (12 Mt) and are projected to remain roughly constant until 2020. 67% from these CO_2 emissions are related to industrial processes; 28% to emissions from other energy industries than heat and electricity generation (refineries etc.), 5% from other sources[7].

Emissions from methane (CH_4) accounted for 6 Mt CO_2e in 2008 and are projected to decline to 5 Mt CO_2e by 2020. Emissions from nitrous oxides were 6 Mt CO_2e in 2008 and are expected to stay almost constant. For the other greenhouse gases (HFCs, PFCs and SF6) an increase of 3% to 1.6 Mt CO_2e in 2020 is estimated (Figure 2.11).

[7] These CO_2 emissions include emissions from waste, emissions from solvent and other product use and emissions from the Austrian military.

Figure 2.11: Reference scenario for other greenhouse gas emissions

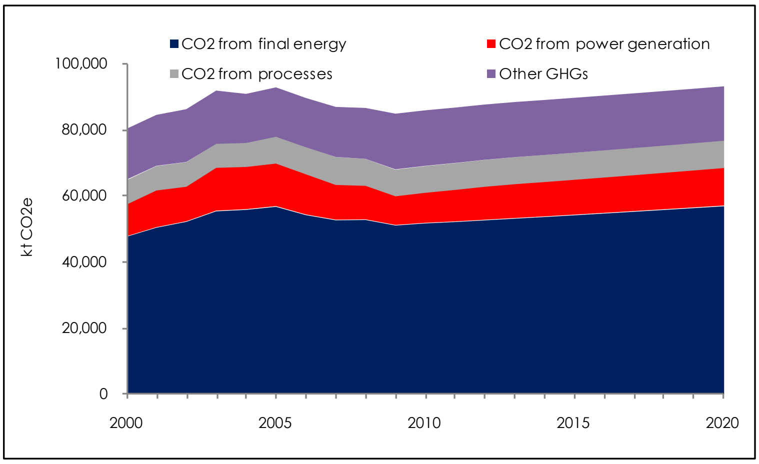


Source: UNFCCC (2010); own calculations.

2.2.4 Total greenhouse gas emissions

Figure 2.12 provides an overview of the development of Austrian greenhouse gas emissions. The biggest share in total greenhouse gas emissions accrues to CO_2 emissions from final energy consumption (61% in 2008). CO_2 emissions from heat and electricity generation accounted for 12% of total greenhouse gas emissions in 2008 and are expected to show the highest increase by 2020. Process related CO_2 emissions and other greenhouse gas emissions contributed 9% and 18% of total emissions. CO_2 emissions from final energy consumption are expected to rise by 8% by 2020; for CO_2 emissions from heat and electricity generation an increase of 11% is estimated. For other GHG and for process-related CO_2 emissions increases of 7% and 3% are estimated respectively.

Figure 2.12: Reference scenario for total greenhouse gas emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

2.2.5 Differences between calculated CO_2 emissions and the national greenhouse gas inventories

The bottom up approach chosen in the project EnergyTransition to calculate CO_2 emissions deviates from CO_2 emissions published in the Austrian greenhouse gas inventories (UBA, 2010, UNFCCC, 2010). In EnergyTransition CO_2 emissions from final energy demand and transformation input are calculated using data from the Austrian Energy Balances (Statistics Austria, 2009a) and applying UNFCCC emission factors for the various energy sources. Process related CO_2 emissions from non-energy consumption are calculated by applying UNFCCC emission factors. Remaining CO_2 emissions from other activities (e.g. refineries) are taken from the national greenhouse gas inventories. Table 2.1 shows Austrian CO_2 emissions in the period 2000 to 2008 according to UNFCCC (2010) and according to the EnergyTransition bottom up approach. Annual deviations range between 1.3 and 2.1 million t CO_2 or between 1.8 and 2.9% respectively. In 2008 CO_2 emissions calculated according to the EnergyTransition approach were 1.3 million t higher than those published by UNFCCC. This has to be kept in mind when interpreting the results of this research project.

Table 2.1: Differences between calculated CO_2 emissions and the national greenhouse gas inventories in kt

	2000	2001	2002	2003	2004	2005	2006	2007	2008
CO_2 emissions UBA	65,799	70,191	72,040	77,840	77,723	79,773	76,687	73,972	73,630
CO_2 emissions EnergyTransition	67,754	72,020	73,717	79,308	79,845	81,677	78,686	75,742	74,964
Difference (in kt)	1,955	1,829	1,677	1,468	2,122	1,904	1,999	1,770	1,333
Difference (in %)	2.9	2.5	2.3	1.9	2.7	2.3	2.5	2.3	1.8

Source: Statistics Austria (2009a, b), UNFCCC (2010), (UBA, 2010); own calculations.

2.3 The "Reduction Triangle" until 2020

In line with the Pacala – Socolow approach the reference scenario is complemented by a reduction path for emissions. Together, the reference scenario and the reduction path define the emission reduction requirement until 2020, the so called "reduction triangle". The reduction path is defined by the targets of the Energy and Climate Package of the European Commission for 2020. For Austria these targets mean an (assumed) emission reduction of 21%[8] in the sectors covered by the European Emission Trading Scheme (ETS) and an emission reduction of 16% in the non-ETS sectors compared to 2005 until 2020.

The project EnergyTransition focuses on CO_2 emissions which have the largest share in GHG emissions[9]. We therefore apply the EU GHG reduction targets for the ETS- and the Non-ETS

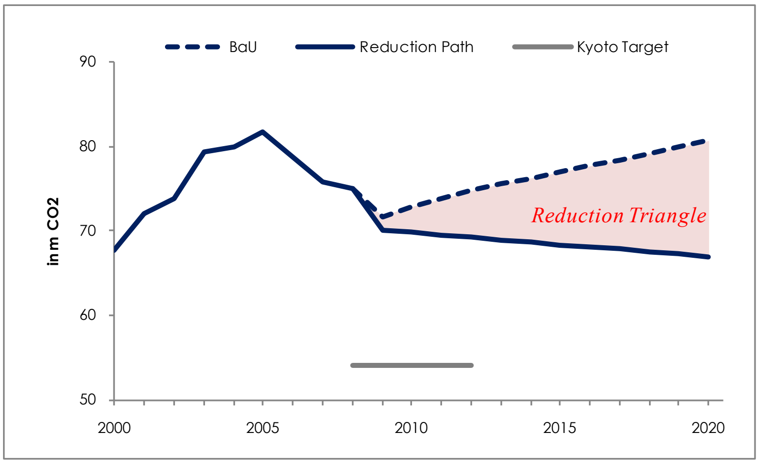
[8] The reduction target of -21% for the ETS sector applies to whole EU and not to individual country targets.

[9] In 2008 CO_2 emissions accounted for 85% of Austrian GHG emissions.

sector to Austrian CO_2 emissions. Under these assumptions a reduction of 8 million t CO_2 emissions compared to 2008[10] is required.

The reference scenario until 2020 (an increase of CO_2 emissions from 75 million t CO_2 in 2008 to 81 million t CO_2 in 2020; see chapter 2.2) and a linear reduction path define the reduction requirement illustrated by the reduction triangle (red area in Figure 2.13). In 2020 a reduction of CO_2 emissions of 14 million t compared to the reference scenario is required[11].

Figure 2.13: Reduction triangle for Austria



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations – The Kyoto target in this graph represents only the reduction requirements for CO_2 based on the assumption that the Austrian Kyoto target is equally distributed over all categories of greenhouse gases.

[10] The reduction requirement for CO_2 with respect to the base year 2005 in the EU Energy and Climate Package amounts to 15 million t CO_2. The significant difference in the reduction requirements with respect to 2005 and 2008 is the result of an overall decrease of CO_2 emissions of 6,7 million t between the two years.

[11] The corresponding reduction target for overall greenhouse gas emissions would be 17 million t CO_2e respectively.

3 Methodological approach for implementing technology wedges in EnergyTransition

3.1 Energy aspects

3.1.1 Modelling energy demand sectors

Technological and behavioural options in the areas buildings, mobility and industry (technology wedges) are each related to different potentials for reducing final energy demand and associated emissions and follow specific storylines. In order to illustrate the cascade of the energy system a common methodological approach for modelling the technology wedges for final energy demand in the project EnergyTransition is therefore necessary.

The method developed in the project EnergyTransition uses five central variables for describing changes in the energy system and in emissions for each technology wedge:

- *S* for energy service,
- U for *effective useful energy*,
- *u* for useful energy intensity (amount of effective useful energy[12] U per service unit S, *u=U/S*),
- *F* for final energy demand, and
- *f* for final energy intensity (amount of final energy F per useful energy, *f=F/U*).

The development of these four central variables until 2020 is expressed in indices with the base year 2008 = 100. The reductions in final energy demand and emissions depend on the development of energy services, changes in useful energy intensity and final energy intensity which depict technological and behavioural changes. The effects on emissions stem from changes in the amount of final energy demand on the one hand and the structure of energy demand by energy source on the other hand (see below).

The central equation for the development of final energy demand is:

(3.1) $$F_{w,t} = \frac{S_{w,t} * u_{w,t} * f_{w,t}}{10{,}000}$$

Final energy demand for a specific activity (*w*) in one year thus results from the amount of energy service demanded (*S*, e.g. living space, person kilometres) multiplied by useful energy intensity (*u*) and final energy intensity (*f*). It has to be noted that not all variables and thus indices have to show a change over time for each technology wedge. The technology

[12] Useful energy U is defined as the portion of final energy which is actually available after final conversion to the consumer for the respective use. In final conversion, electricity becomes for instance light, mechanical energy or heat. The effective useful energy used here considers efficiency factors of application technologies.

wedge specific storyline describes which variables change over time and to what extent. In the storyline the shape of the diffusion path of technologies or behaviour changes is explicitly developed. The diffusion path can take on various forms e.g. linear, exponential or a step function.

Given a certain path for the demand for energy services (determined e.g. by behavioural changes) changes in useful energy intensity over time are one of the determinants of energy demand. Variations in useful energy intensity occur through technological changes like an improvement in the thermal quality of the building stock. These technological aspects are again based on the storylines developed for various activities using a bottom up approach (see storylines for mobility, buildings and industry).

Based on equation (3.1) technology wedges for final energy demand can be expressed using the following variables:

- $\Delta a_{w,t}$ for changes in useful energy intensity and energy services, and
- $\Delta f_{w,t}$ for additional changes in final energy intensity.

Changes in effective useful energy demand compared to 2008 that result either from the use of alternative application technologies (e.g. a building stock of higher thermal quality or light weight vehicles) or from changes in life styles and behaviour ($\Delta a_{w,t}$) are calculated according to equation (3.2):

(3.2) $$\Delta a_{w,t} = \frac{s_{w,2008} * u_{w,2008}}{100} - \frac{s_{w,t} * u_{w,t}}{100}$$

which can be simplified to

(3.3) $$\Delta a_{w,t} = 100 - \frac{s_{w,t} * u_{w,t}}{100}$$

as all variables represent indices with 2008 = 100.

A reduction in final energy demand can also result from an improvement in final energy efficiency. Changes in final energy efficiency ($\Delta f_{w,t}$) – as for example a more efficient heating system – that add to the changes in energy services and useful energy intensity ($\Delta a_{w,t}$) are calculated as in equation (3.4). Based on equation (3.1) $\Delta f_{w,t}$ can be defined as

(3.4) $$\Delta f_{w,t} = \frac{s_{w,2008} * u_{w,2008} * f_{w,2008}}{10,000} - \frac{s_{w,t} * u_{w,t} * f_{w,t}}{10,000} - \Delta a_{w,t}$$

which can be simplified to

(3.5) $$\Delta f_{w,t} = \mathrm{F}_{w,2008} - F_{w,t} - \Delta a_{w,t}$$

with $F_{w,2008} = 100$.

Based on $\Delta\ a_{w,t}$ and $\Delta\ f_{w,t}$ the remaining final energy demand in a given year can be expressed for each technology wedge as presented in equation (3.6):

$$(3.6) \quad F_{w,t} = F_{w,2008} - \Delta a_{w,t} - \Delta f_{w,t} = 100 - \Delta a_{w,t} - \Delta f_{w,t}$$

The reduction in final energy demand by the technology wedge is the sum of $\Delta a_{w,t}$ and $\Delta f_{w,t}$.

From the methodological approach of transforming storylines into a likely path for services, useful energy intensity and final energy intensity expressed quantitatively in indices one can then convert the results into changes in absolute final energy demand (in TJ) compared to 2008 (the last year for which official energy statistics are available) as well as changes compared to the EnergyTransition reference scenario developed for this project (see Part B, chapter 2).

Changes in final energy consumption have to be split up by energy source in order to assess implications for the energy mix as well as associated emission reductions. From this the emission path can then be calculated. In a first step, the energy sources' shares in final energy consumption are calculated:

$$(3.7) \quad s_{w,i,t} = s_{w,i,2008} + \Delta s_{w,i,t}$$

where $s_{w,i,t}$ denotes the share of energy source *i* in year *t* for activity *w*, $s_{w,i,2008}$ denotes the share of energy source *i* in 2008 and $\Delta s_{w,i,t}$ denotes the change of energy source *i*'s share in final energy consumption in year *t* for activity *w* compared to 2008[13]. Changes in the energy sources' shares in final energy consumption are derived from the assumptions made in the storylines regarding technological change and diffusion rates. By multiplying the shares ($s_{w,i,t}$) with absolute final energy consumption (in TJ), for each year changes in final energy consumption by energy source ($\Delta F_{w,i,TJ,t}$) can be calculated for the activities (*w*) using equation (3.8):

$$(3.8) \quad \Delta F_{w,i,TJ,t} = s_{w,i,2008} * F_{w,TJ,2008} - s_{w,i,t} * F_{w,TJ,t}$$

Based on this information the emission reductions compared to the reference scenario and 2008 can be calculated using emission factors from UNFCCC (2010). Changes in CO_2 emissions ($\Delta C_{w,t}$) are calculated by multiplying changes in absolute final energy consumption with the corresponding emission factor (c_i) for each energy source:

[13] In each year $\sum_i \Delta s_i = 0$.

(3.9) $\Delta C_{w,t} = \sum_i (c_i * \Delta F_{w,i,TJ,t})$

The common methodological approach for the areas mobility, buildings and industry ensures the consistent integration of all technology wedges into the cascade of the energy system. A combination of technology wedges in order to achieve certain emission targets e.g. the emission target resulting from the EU Energy and Climate Package then has to identify technology wedges that are additive. Combining e.g. a technology wedge "100% passive houses" in newly constructed buildings with a wedge "substitution of heating systems in conventional new buildings" is not feasible. In contrast "100% passive houses" in new construction and thermal improvement or substitution of heating systems in the building stock are fully additive.

3.1.2 Modelling energy supply

For technology wedges in the area of energy supply a modified modelling approach is necessary as changes in the level of transformation input and in emissions are the result of changes in transformation output – which is in turn driven by final energy demand – and in the fuel mix used to generate power and heat. Technology wedges that are targeted at the substitution of electricity and heat output from conventional plants by energy from low carbon technologies can be expressed by the following variables:

- $TO_{i,j}$ for transformation output from energy source *i* in plant type *j*,
- $TI_{i,j}$ for transformation input of energy source *i* in plant type *j*
- $e_{i,j}$ for transformation efficiency of plant type *j* using energy source *i* (amount of transformation output per transformation input, $e_{i,j}=TO_{i,j}/TI_{i,j}$).

The development until 2020 of these central variables is again expressed in indices (2008 = 100). Changes in transformation input depend on changes in transformation output on the one hand and changes in transformation efficiency on the other hand.

The central equation for technology wedges for energy supply hence can be written as

(3.10) $TI_{w,i,j,t} = \frac{TO_{w,i,j,t}}{e_{w,i,j,t}} * 100$

Equation (3.10) depicts the relationship of the three key variables. For a specific activity (*w*) transformation input of an energy source in a certain type of plant in a given year results from transformation output divided by transformation efficiency.

Using equation (3.10) total transformation efficiency can be written as

(3.11) $e_{w,t} = \frac{TO_{w,t}}{TI_{w,t}}$,

where $TO_{w,t} = \sum TO_{w,i,j,t}$ and $TI_{w,t} = \sum TI_{w,i,j,t}$.

Based on equations (3.10) and (3.11) technology wedges for energy supply can be expressed as combined changes in transformation output and transformation efficiency ($\Delta t_{w,t}$) which gives the reduction in transformation input by the technology wedge

(3.12) $\Delta t_{w,t} = \frac{TO_{w,2008}}{e_{w,2008}} * 100 - \frac{TO_{w,t}}{e_{w,t}} * 100$

which can be simplified to

(3.13) $\Delta t_{w,t} = 100 - TI_{w,t}$

using equation (3.10) and the fact that all values represent indices with 2008 = 100.

Remaining transformation input in a given year can be expressed for each technology wedge using $\Delta t_{w,t}$:

(3.14) $TI_{w,t} = TI_{w,2008} - \Delta t_{w,t}$

In order to assess the effects of the technology wedge on CO_2 emissions in a given year, changes in the index have to be translated into absolute transformation input ($TI_{w,i,TJ,t} = \sum_j TI_{w,i,TJ,j,t}$) for all energy sources.

(3.15) $\Delta TI_{w,i,TJ,t} = \frac{TI_{w,i,2008} * TI_{w,i,TJ,2008} - TI_{w,i,TJ,t} * TI_{w,i,TJ,2008}}{100}$

Based on this the emission reductions compared to the reference scenario and to 2008 can again be calculated using emission factors from UNFCCC (2009). Changes in CO_2 emissions ($C_{w,t}$) are calculated by multiplying changes in absolute transformation input (in TJ) with the corresponding emission factor (c_i) for each energy source (equation (3.16)).

(3.16) $\Delta C_{w,t} = \sum_i (c_i * \Delta TI_{w,i,TJ,t})$

3.1.3 Combining energy demand and energy supply technology wedges

Although the modelling approach for energy supply deviates from the modelling of technology wedges for the final demand sectors one can reconcile the common idea by interpreting final energy demand resulting from technology wedges in mobility, buildings and industry as proxy for S. Thus, the potential or necessity for technology wedges in the area energy supply is not independent from activities in the sectors constituting final energy demand.

For ‘filling’ the reduction triangle – i.e. for achieving a certain emission reduction by 2020 – a combination of different technology wedges has to be selected. The aggregate emission reduction of the combined wedges in year *t* is the sum of the individual emission reductions and can hence be written as

(3.17) $\Delta C_t = \sum_w \mathrm{C}_{\mathrm{w,t}}$

3.2 Economic aspects

The extended technology wedges approach as applied in the project EnergyTransition extends the original method by Pacala and Socolow also with respect to economic analysis.

EnergyTransition aims at analysing economic effects of the investment phase until 2020 based on an input output analysis. Furthermore, impacts of the operating phase for the considered technology wedges are discussed. The macroeconomic effects are analysed within a static input-output analysis, thus dynamic effects are not covered. Dynamic effects would be e.g. effects on private consumption if disposable income is used for housing investment. Another aspect not covered are the dynamic effects resulting from cost savings in the operating phase.

For a sample of technologies a microeconomic cost appraisal based on capital user costs complements the results of the input output calculations. For both the macroeconomic investment and operating effects as well as for the microeconomic analysis the system boundaries for each technology wedge have to be considered.

3.2.1 Analysis of the investment and operating phase

For the period until 2020 annual investment requirements[14] are estimated for each technology wedge and each storyline. In order to assess the domestic economic implications of the implementation of the technology wedges, investment costs are split up into sectoral investment shares as well as an assessment of the import share. The diffusion of technologies over time is defined by the storyline and can follow different paths: linear, exponential, stepwise or other.

For the estimation of output and employment effects a multiplier analysis is conducted. These calculations show which demand effects follow from an investment activity in a certain sector. This multiplier analysis represents a static input-output approach using the input-output Table by ÖNACE categories as published by Statistics Austria (2009c).

The input-output Table depicts the intersectoral linkages of the Austrian economy and shows the distribution of output of each sector with respect to the sectors receiving the output on the one hand and the intermediaries received by the sector from all other sectors in the

[14] Investment costs for the technology wedges are assessed as total costs as well as additional costs compared to a respective reference technology.

economy on the other hand. These inter-sectoral linkages are described in the technology matrix of the input output table. Total production of one sector therefore is the sum of all goods delivered to other sectors and the categories of final demand (e.g. investment). Viewed from the supply side, total production of a sector is the sum of the received intermediaries from other sectors and value added. The input output Table delivers multipliers which specify total production of goods and employment in the economy (i.e. through the production chain) stemming from the demand for one unit produced in a certain sector.

The multiplier effects of the static analysis are to be interpreted as "first round" effects illustrating production of goods and employment stemming from final demand (investment) as well as from the production of necessary intermediaries. Not covered by the static input-output approach are macroeconomic effects or induced effects due to an increase in income and higher consumption spending or replacement effects that can result in positive demand effects ("secondary effects").

For the analysis of economic effects of investments related to the implementation of a set of technology wedges, the investment cost for an "average" year split up by sectoral shares for each technology wedge are the starting point for the static input output analysis. Thus, the direct and indirect effects of these investments are calculated.

Direct effects apply to the sector where the investment is made; indirect effects are determined by the intersectoral linkages. The total effects are the sum of direct and indirect output and employment effects of the investment in all sectors.

The economic analysis of the investment phase in the transition of the energy system is complemented by data for the operating phase. These data cover cost categories like maintenance, personnel, insurance, fuels etc. The development of operating costs mirrors again the diffusion path of technologies. For the operating phase "additional costs" are calculated, which are the difference between operating costs of the respective reference technology (e.g. a conventional building) and operating costs of the wedge technology (e.g. a passive house). For many technology wedges these additional costs will be negative because of the energy (cost) savings resulting from the application of more efficient technologies as compared to the reference case.

From a macroeconomic perspective it is of interest how the changes in the energy system as analysed within the project EnergyTransition translate into savings in energy costs. These calculations can be derived from a comparison of final energy demand and transformation input by energy source in the reference scenario and the corresponding values that result from a combination of technology wedges.

3.2.2 Microeconomic cost appraisal

Apart from the estimates of macroeconomic effects of the investment phase of the technology wedges, a sample of technologies is selected for which a microeconomic cost appraisal is conducted. This method enables a better comparison of the cost impacts of the technology wedges considered, allowing an integrated analysis of the investment and operating phase. Key variables for this calculation are:

- service life of the technology
- investment costs
- interest rate and
- operating costs (energy prices, maintenance costs etc.)

For an integrated perspective of the investment and operating phase the service life of the technology represents a reasonable parameter for a breakdown of investment costs on an annual basis. One has to consider that the calculation results are sensitive to assumed parameters like service life, interest rate or fuel prices. A pragmatic approach is taken with respect to price changes: constant prices are assumed for investments as well as for energy and other operating expenditures, which translates into constant relative prices. In order to illustrate the sensitivity of results with respect to the assumptions for the input parameters, exemplarily different interest rates or an anticipated decrease in investment costs are used in the calculations.

The cost appraisal is a comparative cost method, and is based on the following equation

$$C = C_k + C_f + C_v$$

where C_k denotes the user costs of capital (annual interest rate and depreciation of the investment (IC) over the assumed service life (n), $C_k = r*IC + IC/n$), C_f denotes other fixed costs like maintenance and upkeep costs and C_v denotes variable costs.

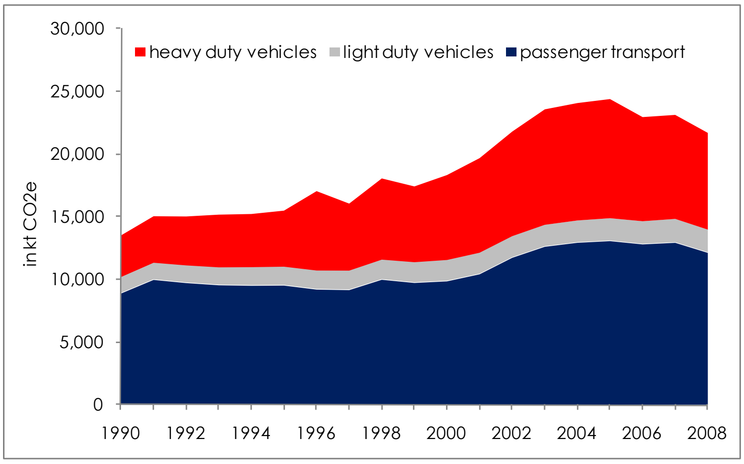
Thus, it can be illustrated to which extent the costs of various technological options (e.g. technologies based on fossil fuels or renewable energy) differ, given certain assumptions. It can also be illustrated to what extent savings in energy costs during the operating phase can offset higher investment costs of energy efficient technologies over a certain time span (that is the service life of technologies). The relevant data for the listed variables again are compiled in the storylines for the respective technologies.

4 Energy services and implementing the concept of technology wedges for Workpackage 1 – Mobility

4.1 Introduction

The transport sector is responsible for a rising share in Austrian greenhouse gas emissions (GHG), most recently 26% (respectively 30% of CO_2 emissions only) in 2008 (Anderl et al., 2010a). According to the UNFCCC accounting principles transport emissions are calculated based on total fuel sales in Austria. However, not all fuels sold in Austria are used within Austrian borders, but may be used when driving abroad (and thus GHGs are emitted abroad ('fuel export in vehicle fuel tanks')). Between 1990 and 2008 transport GHG emissions rose by 60% (Anderl et al., 2010a). The major part in 2008 is due to road transport (98%), of which 55% arise from passenger transport and 43% from heavy and light duty vehicles. Rail, navigation, aviation and pipelines account for 2% of the GHG emissions. The trend of road transport GHG emissions is given in Figure 4.1. Emissions from passenger transport contain those from passenger cars, mopeds and motorcycles; heavy duty vehicles in this Figure (which is based on the energy balance categories) also include buses.

Figure 4.1: Emissions from road transport (1990-2008)

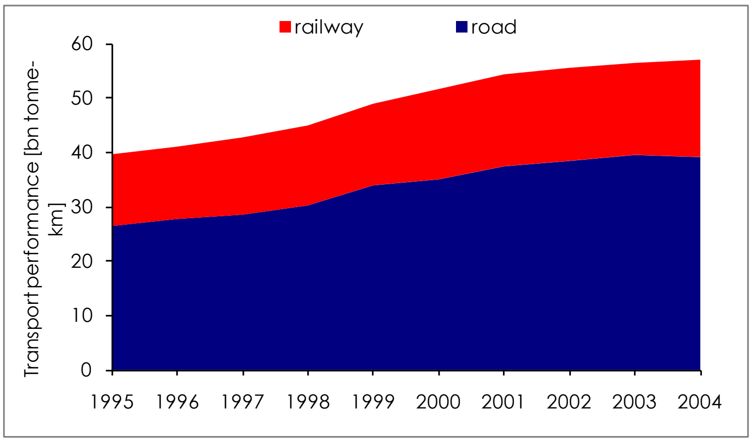


Source: Anderl et al. (2010a).

The significant growth in emissions is in particular due to the increase in freight transport. Between 1990 and 2008 GHG emissions from heavy duty vehicles increased by nearly 132%.

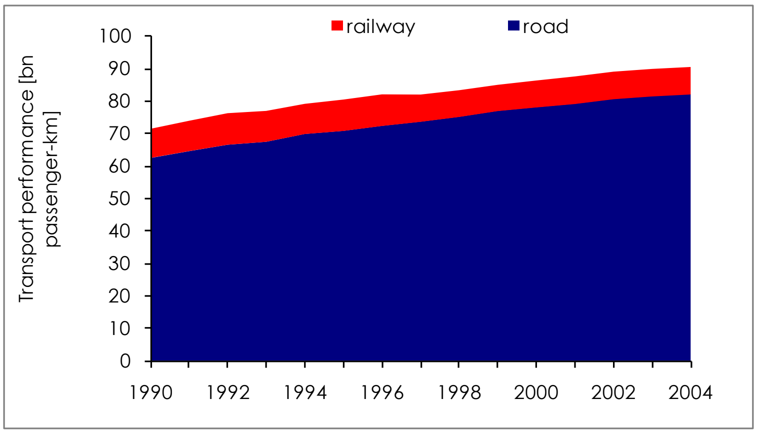
Between 1995 and 2004 freight transport performance (i.e. tonne-kilometres) increased by 48% and passenger transport performance (i.e. passenger-kilometres) by 16% (BMVIT, 2007). The trends are shown in Figure 4.2 and Figure 4.3. The trend in freight transport is in particular the consequence of the increase in the international division of labour and the fragmentation of production.

Figure 4.2: Trends in freight transport performance (1995-2004)



Source: BMVIT (2007).

Figure 4.3: Trends in passenger transport performance (1990-2004)

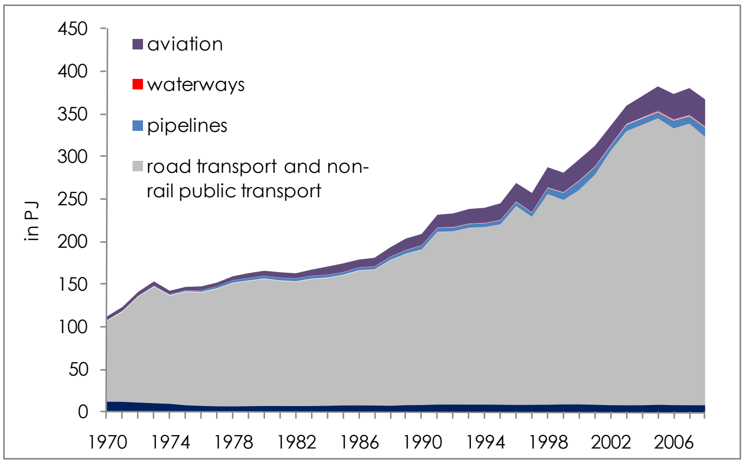


Source: BMVIT (2007).

Transport is responsible for 34% of total final energy consumption in Austria (Statistics Austria, 2009a), with road transport taking up the largest share (86% of transport final energy demand). Transport is almost exclusively dependent on non-renewable fossil fuels. Technological progress (i.e. gains in vehicle efficiency) has not been sufficient so far to reverse the trend of growing absolute energy demand in transport.

The Austrian energy balances classify transport along the following categories: land transport, railways, aviation, waterways and pipelines. The category 'land transport' comprises road passenger transport (motorised individual and public transport), all other non-rail public transport, and road freight transport.

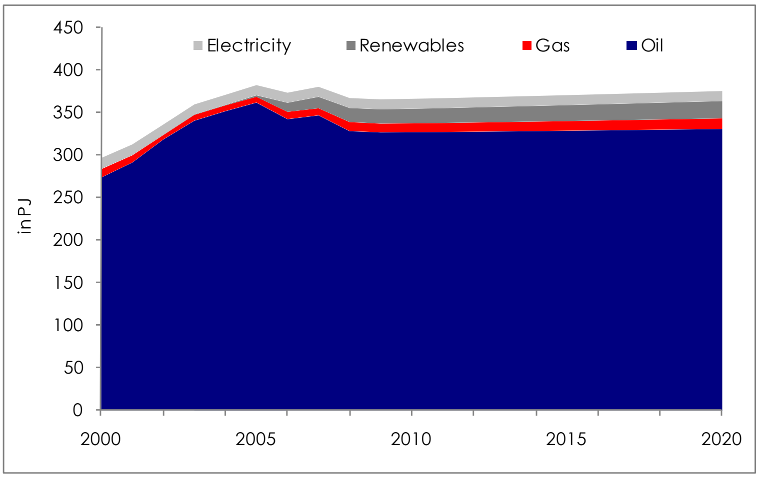
Figure 4.4: Final energy consumption of the transport sector by means of transport (1970-2008)



Source: Statistics Austria (2009a).

The prevalent dependency on fossil fuels (diesel and gasoline) becomes obvious in transport final energy demand by primary energy source. The projection of final energy demand in useful energy category traction (transport sector) by energy source is given in Figure 4.5.

Figure 4.5: Reference scenario for final energy consumption in useful energy category traction by energy source (2000-2020)



Source: Statistics Austria (2009a, b); own calculations.

The EnergyTransition reference scenario for final energy demand until 2020 follows the trends from past years and shows an increase of 2% between 2008 and 2020. The transport sector demands the largest share of final energy (with 34% in 2008) followed by the production sector and households and this trend continues. Furthermore the dependency on fossil fuels means formidable challenges this sector has to meet. The following section highlights options to commence technological and behavioural changes that are able to initiate a trend reversal.

4.2 Storylines for technology wedges in the transport sector

For determining final energy consumption we start by considering energy services as the first and welfare relevant step in the energy cascade (on the conceptual rationale see Part A in this study). Thus, in this research project the recommendations for restructuring the energy system start from energy services. The volume and mix of primary energy inputs to satisfy the demand for energy services is observable at the other end of the energy cascade, after considering the range of different transformation and application technologies.

There are various definitions for energy services in transport. In a common and rather technical definition transport energy services are frequently determined as trip distances travelled in passenger and freight transport. Indicators are the mileage (in terms of vehicle kilometres) or, alternatively, the transport performance in terms of passenger kilometres for passenger transport and tonne-kilometres for freight transport.

Transport performance can be further subdivided along the following lines:

- by different spatial structures (agglomeration, villages, rural areas)
- by different travel distances (e.g. up to 2 km, up to 10 km, up to 100 km)
- by different transport modes (car, train, bus)
- by different trip purposes (work, leisure, business etc.)

The actually provided service – that in economic terms leads to transport related benefits – could be defined as the feasibility to reach a person, a good or a service. Transport per se generally does not yield any benefit, rather it is a means to provide access to persons, goods and services that are provided at different distances from the consumer's or producer's location.

Transport originates by linking all the important functions, activities and amenities of life, such as work, housing, leisure, education etc. Depending on the spatial distribution of housing, work, shopping etc. the energy input to provide a certain mobility service may be very low or very high. For example for someone who lives in the city getting a loaf of bread might require very low energy input as one buys it at the bakery nearby while for someone who lives at the countryside this might be related to the use of a car.

Starting from the analysis of the status quo of transport patterns the targets for a transport system leading to a reduction of energy demand are (1) to avoid redundant and/or compelled mobility (e.g. reducing urban sprawl, use of logistics), (2) to introduce new mobility concepts (e.g. flexible, available mobility services or the integration of private and public transport in a more efficient way) and (3) to provide attractive alternative technology concepts (e.g. electric vehicles, ultra-light vehicles).

4.2.1 General assumptions underlying the storylines

The determination of energy and emission reduction potentials for different technology wedges described in the corresponding storylines is based on trends in motor vehicle stock and average mileage. We start from recently observed transport performance in passenger transport (pkm) and freight transport (tkm) for the different individual passenger transport modes (motorised and non-motorised), public transport and freight transport (rail and road) when calculating emission reduction potentials (Käfer et al., 2009).

For Austrian transport data a diversity of data bases is available. Quite some data bases show different figures for current transport levels, due to different compilation and estimation methods. By means of the VPÖ2025+project (Käfer et al., 2009) a consistent data base was generated for freight and passenger transport, in particular for road and rail transport. Table 4.1 gives the 2005 figures for freight transport in terms of transport volume for road, rail and waterway, as well as transport performance for road and rail (VPÖ2025+). The data for waterway and pipelines are derived from Käfer et al. (2009) and BMVIT (2007). Table 4.2 gives the corresponding data for passenger transport in 2005.

Table 4.1: Transport volume and performance in freight transport 2005

	transport volume (mil.tonnes)	mileage (mil. vehicle-km)	transport performance (mil. t-km)
road	434.2	4,383	35,973
rail	90.8		17,790
waterway	14.9		3,168
pipeline	64.5		15,484

Source: Käfer et al. (2009), BMVIT (2007).

Table 4.2: Transport volume and performance in passenger transport 2005

	number of trips (mil.)	mileage (mil. vehicle-km)	transport performance (mil. passenger-km)
road	15.5	61,362	73,635
public transport	5.0		24,785
rail	n.a.		9,508
bus	n.a.		11,507
pedestrian and bike	6.5		2,430
total	27.0		100,850

Source: Käfer et al. (2009); own calculations.

In the storylines for the technology wedges in the transport sector reduction potentials for all transport categories are considered except for air traffic and pipelines as we seek quantitatively reliable results and thus employ the passenger and freight transport modelling approaches available in Austria, all of which, however, at least to date exclude air and pipeline.

The projections for the stock of motor vehicles as well as energy intensities (GWh/km) and emission factors (CO_2/kWh) are based on Hausberger (2010). Using the energy intensities for different modes and energy sources and respective emission factors, total energy use and emissions can be calculated. In this 'bottom-up' approach energy and emissions are calculated based on the actual passenger kilometres or tonne-kilometres driven in Austria and differ from data from the Austrian energy balances of Statistics Austria which include fuel that is sold in Austria but not necessarily used within Austrian borders ('fuel export in vehicle fuel tanks').

Table 4.3: Final energy consumption for passenger and freight transport 2008 (bottom-up calculation)

	Final energy [PJ]
passenger transport*	161
freight transport	54
total	214

Source: Own calculations. – * Not including aviation.

The main general assumptions underlying the calculations for the reduction potentials of technology wedges in each storyline concern:

- trends in the vehicle stock (diesel vs. gasoline engines)
- trends in modal share (in passenger and freight transport)
- trends in the occupation rate in passenger transport and loading rate in freight transport
- implementation of the EU regulation on 'setting emission performance standards for new passenger cars'

In the following these underlying assumptions are explained in detail.

First, there has been a trend towards diesel engines in passenger transport in the past – due to a price differential between diesel and gasoline. The recent past since 2003 is characterised by a trend reversal in Austria which shows that – unlike in the past 10 years – the percentage of diesel engines is declining and the percentage of gasoline engines is increasing again. This is due to the harmonisation of fuel prices (mainly caused by an alignment of tax rates). Another reason may be the bad image of diesel engines because of the increasing environmental problems with particulate matters especially in urban areas. Furthermore production costs for diesel engines due to the stricter NO_x emission standards of the EURO 6 legislation will increase in the future, contributing to the trend reversal considered when calculating energy and emission reduction potentials in each storyline.

Second, the share of public transport has been decreasing in the past (shifting energy saving transport to more energy intensive transport). This trend is assumed to continue and is leading to a decrease of the share of public transport (measured in passenger kilometres) by 2 percentage points between 2008 and 2020 (from 26% in 2008 to 24% in 2020). In freight transport the trend in modal split between rail and road transport is assumed to continue implying a decrease in the share of railway in transport performance (tkm) by about 2 percentage points between 2008 and 2020 (from 32% in 2008 to 30% in 2020).

Third, trends in the vehicle occupation rate in passenger transport and in loading rates in freight transport are pursued. The occupation rate (passengers per vehicle) of 1.2 will decrease slightly by 3% between 2008 and 2020. Reasons might be demographic trends like the increase of single households in the future or the increase of the number of vehicles per household. In freight transport it is assumed that the loading rate (tons per vehicle) increases by 8% between 2008 and 2020 (starting from 8.8 t/vehicle in 2008 to 9.5 t/vehicle in 2020). Fourth, central parameters for the calculation of the emission reduction potentials for different technology wedges are the underlying emission factors for each transport category. The path of future development of emission factors for the Austrian fleet is highly dependent on the implementation of EU regulation (EC) No 443/2009 (European Commission, 2009) on "setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO_2 emissions from light-duty vehicles". The regulation prescribes "mandatory reductions of emissions of CO_2 to reach an objective of 130 g CO_2/km for the average new car fleet by means of improvements in vehicle motor technology as the immediately relevant goal. From 2020 onwards, the regulation sets a target of 95 g CO_2/km. As the regulation is mandatory for the EU member states the reduction potentials in all technology wedge scenarios for mobility are calculated under the assumption that the regulation is fulfilled in Austria. The underlying emission factors for the Austrian fleet for the case with implementation of the regulation are given in Table 4.4. The implementation of the EU regulation is acknowledged in each storyline.

Table 4.4: Emission factors underlying the calculations for emission reduction potentials (with EU regulation implemented)

Emission factors [gCO_2/vehicle-km]	**2008**	**2020**
passenger transport		
gasoline	183	134
diesel	159	134
electric*	44	44
plug-in hybrid	126	97
freight transport (heavy duty vehicles)		
gasoline	451	451
diesel	685	682
Emission factors [gCO_2/passenger-km]		
public transport		
bus	32	31
rail	12	11

Source: Hausberger (2010); own calculations. – *We use the current (2008) Austrian electricity production mix for this emission factor, and assume it constant up to 2020. Any increase in the share of renewables in electricity production would reduce this emission factor, and vice versa.

Before describing the storylines and the calculation of each technology wedge we have to describe the EnergyTransition methodology concerning energy indicators in the transport sector. The EnergyTransition methodology utilises indices (relating to 2008) to illustrate the likely development up to 2020 for each technology wedge as described in the storylines. Technology wedges in the storylines either refer to the total transport sector or only to segments of it (passenger or freight transport). For example alternative fuels concern both the passenger and freight transport sector, while for an enhancement of public transport only the passenger transport is relevant. Depending on the storyline and the segments considered indices are calculated. They may thus refer only to these segments of overall transport.

As explained above the energy service in mobility has the objective to ensure access to persons, goods and services, and is thus needed for connecting important functions and amenities of daily life. According to this definition the energy service is sought to ensure the level of access not to decline over time in all storylines. To simplify the measurability, energy service (*S*) is expressed by means of the variables vehicle kilometres, passenger kilometres and tonne-kilometres. However, note that vehicle kilometres or passenger kilometres may be reduced or shifted in the storylines still leading to the same access to persons or goods with only reduced energy consumption and reduced CO_2 emissions. In particular this is the case with improved spatial planning, where the same access is enabled with less passenger kilometres.

We assume that demographic developments will give rise to more trips and more goods have to be transported over time, thus *S* is rising. The implicit final energy demand for providing the energy service is *F*. The effective useful energy (*U*) can be calculated by using the energy intensity factor for final energy *f* (*F/U*) for different transport modes and vehicle categories. The corresponding energy intensity for useful energy is *u*, i.e. *U/S*. The above described general assumptions underlying transport development – a decreasing share of public transport over time, a shift from diesel to gasoline engines the latter being less efficient and a decrease in vehicle occupation rate due to demographic changes – lead to an increasing *u*, if there are no additional effects in the particular technology wedge influencing this indicator.

Given the underlying general assumptions the technology wedges aim at three major effects. First, transport performance (p-km or t-km) will be reduced. Second, there is a shift between transport modes e.g. a shift from energy intensive modes like passenger cars to energy saving modes like bike and pedestrian. Third, changes come from efficiency gains because of improved motor technology and/or decreased mass of vehicles. How these effects can be realised is described in each of the storylines for the different technology wedges.

The magnitude of the effects is expressed in terms of the energy indicators for each storyline. Changes over time in useful energy intensity and energy services for each storyline are incorporated in Δa and changes in final energy intensity are given in Δf (for a definition of Δa and Δf see Part B, chapter 3 on the methodology of implementing technology wedges).

In the following we present the different technology wedges and storylines in the transport sector by describing the benchmark data, changes in energy indicators and changes in CO_2 emissions.

4.2.2 *Technology Wedge M-1: Promotion of an efficient transport saving land use*

Spatial planning measures and economic instruments can be reformed in a way that they counteract urban sprawl and lead to settlement patterns with considerably improved access to public transport. Dense and mixed settlement patterns providing several functions of living close-by lead to shorter distances in daily trips.

Friedwagner et al. (2005) evaluated the transport effects of denser regions in the surroundings of Linz and Wels in Upper Austria. Using a transport model the transport volume development between 1991 and 2001 was compared to an alternative scenario, in which the total number of people that had moved during this period to areas with low residential density and insufficient supply of public transport has been shifted to favourable areas with high density. As a consequence the motorised individual transport performance of the population moved was found to be reduced by 16%, and accompanied by an increase in public transport performance by 7%. We scaled up these results of Friedwagner et al. (2005) to the Austrian level. For that end the number of people that are – in the current trend – moving to areas with low residential density had to be determined. A detailed calculation for one representative Austrian province, Styria, was conducted and extrapolated from the Styrian results to each of the other provinces. In the period between 2009 and 2020 in Styria about 755,350 people are expected to move. This number is determined using the statistics of moves between 2004 and 2008 in Styrian communities and extrapolating the trend until 2020, applying moving rates (as a share of total population) to the predicted population in 2011, 2016 and 2021 in each community (data provided by Statistics Styria). Then the share of people that are moving to areas with low residential density had to be determined. Therefore a minimum level of population density for areas to which the population preferably moves to had to be set. An indicator of public transport supply is used, in particular a supply of at least one public transport stop per square kilometre, which is served by at least ten departures daily. With that a share of 39 % of people was determined who moved anyway but who had to be shifted in their move to favourable areas. While these data were available at the community level for Styria, no access to data of similar quality for the remaining Austrian communities was available. Therefore Styrian results were scaled up to each of the other provinces using weights of overall provincial residential density. Vienna is not taken into consideration, because there are no rural regions in which the supply of public transport is not sufficient. Thus, in total 1 725 880 people in Austria were determined to move to areas with low residential density between 2009 and 2020, representing the potential of redirecting their move to areas with high residential density. For the case that this potential is fully exploited, Table 4.5 summarises the characteristics of the technology wedge.

Table 4.5: Summary Table for Technology Wedge M-1

Promotion of an efficient transport saving land use	
Energy service*	Reduction of individual motorised transport by 3.5 billion pkm and an increase of public transport by 201million pkm in 2020
Technology/ life style	Improved spatial planning
Required capacity increase*	Not applicable
Diffusion path	Quadratic
Total investment	578 million € by 2020
Total operating costs	25 million € in 2020
Additional operating costs	-205 million € in 2020
Emission reduction*	0.4 million t CO_2 in 2020

*Compared to reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge M-1

Table 4.6 summarises the change in the energy indicators in Technology Wedge M-1. The energy service S is increasing by 8% until 2020 compared to 2008 (whereas it would have increased by 11% in the reference case without this wedge). An improved spatial planning reduces transport performance until 2020 compared to a development without implementing better spatial planning, while the access to persons, goods and services remains the same. The general overall assumptions, in particular of changes in demography (see chapter 4.2.1), lead to an increase in S up to 2020, but this increase of S (S being measured in passenger kilometres) is less intense in the present technology wedge. Useful energy intensity (u) is increasing by 4% compared to 2008. Even though we observe a lower demand for energy due to transport saving land use, u is still increasing, because this effect cannot compensate the underlying trend in transport development reflected in the general assumptions (see chapter 4.2.1). However, final energy intensity, that is final energy per service, is decreasing by 19% due to the improvement of vehicle efficiency which is assumed in the storyline according to the EU regulation on the emission performance standards for new passenger cars.

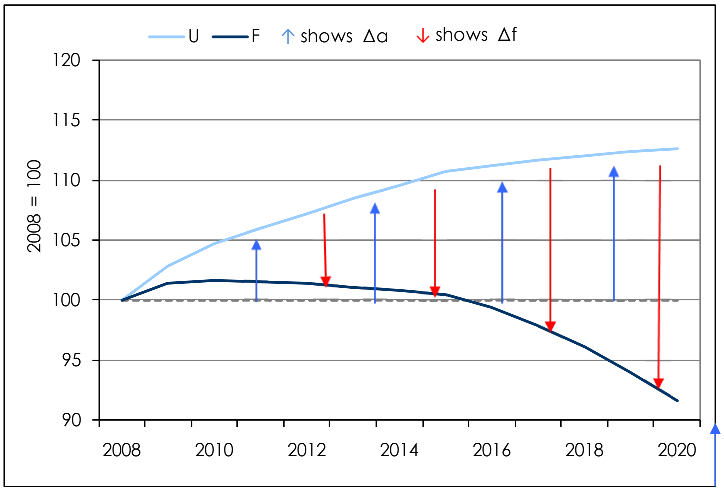
Table 4.6: Technology Wedge M-1: Summary of energy indicators

Promotion of an efficient transport saving land use	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	8	108
Energy Intensities			
Useful Energy Intensity (u)	100	4	104
Final Energy Intensity (f)	100	-19	81
Final Energy (F)	100	-8	92

Source: Own calculations.

Figure 4.6 illustrates the changes in final energy demand over time compared to 2008. Δa expresses the change in S and u. The change is positive, because S and u are increasing over time as just described above. Δf expresses the change in final energy (F) due to a change in final energy intensity f. These two effects combined lead to a reduction of final energy demand (F) by 8% compared to 2008. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.6).

Figure 4.6: Technology Wedge M-1: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity (Δa would have been larger without this wedge). Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.7.

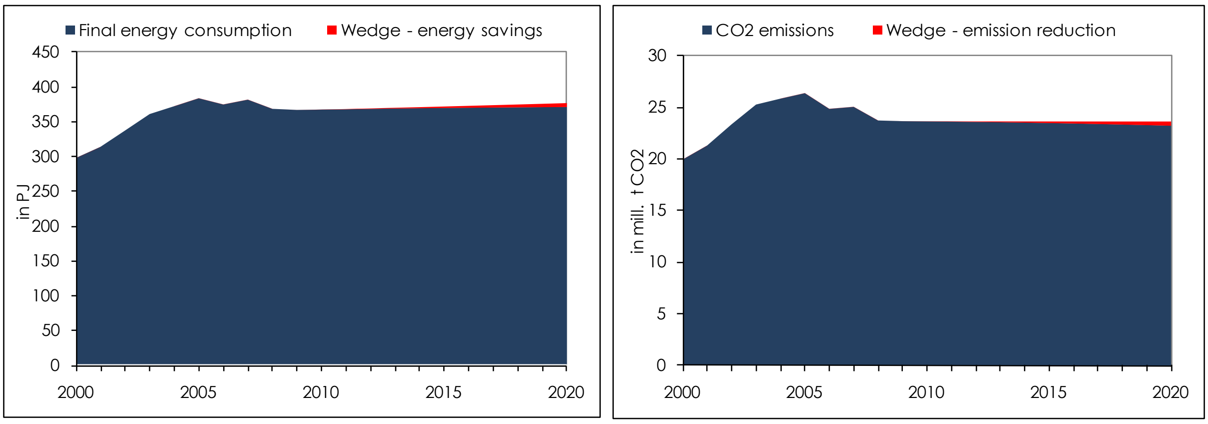
Table 4.7: Technology Wedge M-1: Effects on fuel mix

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.4	88.1
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.0	3.1
Total	100.0	0.0	100.0

Source: Statistics Austria (2009); own calculations.

Table 4.8 and Figure 4.7 show the effects of the implementation of Technology Wedge M-1 on final energy demand and CO_2 emissions in relation to the reference scenario (as described in Part B, chapter 2). 1.5% of final energy demand and accordingly about 400 kt CO_2 can be reduced in 2020 compared to a reference path without measures.

Figure 4.7: Technology Wedge M-1: Effects on final energy consumption and CO_2 emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.8: Technology Wedge M-1: Effects on final energy consumption and CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008 in PJ	2020			2008 in mt	2020		
			Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %		in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	325.30	-5.37	-1.6	23.13	22.54	-0.40	-1.7
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.07	-0.27	-1.3	0.00	0.00	0.00	0.0
Electricity	11.56	11.62	0.03	0.2	0.00	0.00	0.00	0.0
Total	366.54	369.20	-5.61	-1.5	23.70	23.21	-0.40	-1.7

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

Spatial planning measures, economic instruments and funding schemes have to be reformed in order to achieve an efficient transport saving land use. Adjustments of legal frameworks imply administrative effort and are not directly associated with additional costs.

The reduction of transport performance due to denser spatial patterns reduces transport expenditures. Reduced expenditures (variable costs) per saved vehicle-km or passenger-km are determined using energy prices of 2008 and the results of the Household Budget Survey 2004/05 by Statistics Austria. Data from the Household Budget Survey are adapted to the year 2008 using the consumer price index for transport. The variable costs amount to 10.6 cent per vehicle-km for gasoline vehicles, 8.6 cent per vehicle-km for diesel vehicles and 0.3 cent per passenger-km in public transport. Table 4.9 gives the estimated reduction in operating costs by 2020 induced by an efficient land use. Technology wedge M-1 not only covers a reduction of passenger-kilometres for motorized transport but there is also an increase in the demand of public transport of 201 million passenger kilometres in 2020. To ensure the necessary capacity of public transport, an increase in public transport investment of 48 million € per year is needed, mainly in the sector construction (59%), marketing (19%) and other transport equipment e.g. trains (21%) (see Table 4.10). Other investment enters into the sector metal products and the sector for communication equipment. Individual motorised transport consumer expenditures are reduced by 230 million € in 2020. Additional operating costs, i.e. the net sum of reduced consumer expenditures and increased operating costs for public transport as a result of the rising demand for public transport are given in Table 4.9. Operating costs for public transport are usually available in € per train-kilometre or bus-kilometre. For our calculations operating cost increases due to increased demand in public transport is expressed in passenger kilometres, i.e. cost rates per p-km are used. These are derived from total train- and bus-kilometres and total passenger kilometres for different transport modes (OEBB, 2008 and Grazer Verkehrsbetriebe, 2008).

Table 4.9: Technology Wedge M-1: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Inv estment costs	48	48	48	48	48	48	48	48	48	48	48	48
Additional Costs	48	48	48	48	48	48	48	48	48	48	48	48
Operating costs	10	11	13	14	15	17	17	19	21	23	24	25
Additional Costs	8	4	-4	-14	-29	-47	-69	-92	-118	-145	-175	-205

Source: Statistics Austria (2006); own calculations.

Table 4.10: Technology Wedge M-1: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	59,0	0,0	59,0	0,0
Fabricated metal products, except machinery and equipment	0,23	0,1	0,23	0,1
Printed matter and recorded media	19,4	4,7	19,4	4,7
Other transport equipment	21,2	16,5	21,2	16,5
Radio, television and communication equipment and apparatus	0,16	0,1	0,16	0,1
Total	100,0	21,4	100,0	21,4

Source: Own calculations.

Additional operating costs are the result of two effects: one cost effect results from the increased provision of public transport i.e. maintenance costs and other transport services (including variable cost segments arising from the provision of public transport, e.g. personnel costs) and the second cost effect arising from savings for private consumers that switch from private to public transport(i.e energy, maintenance, repair) (see Table 4.11).

Table 4.11: Technology Wedge M-1: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Maintenance and other transport services (public transport)	100	10
Energy		-99
Maintenance (individual transport)		-7
other services relating to vehicle operation		-4
Total	100	-100

Source: Own calculations.

4.2.3 *Technology Wedge M-2: Improvement of public transport*

The storyline for this wedge covers an increase in the share of public transport (transport performance in passenger kilometres) by 3 percentage points by 2020. The characteristics of the wedge are summarised in Table 4.12.

Table 4.12: Summary Table for Technology Wedge M-2

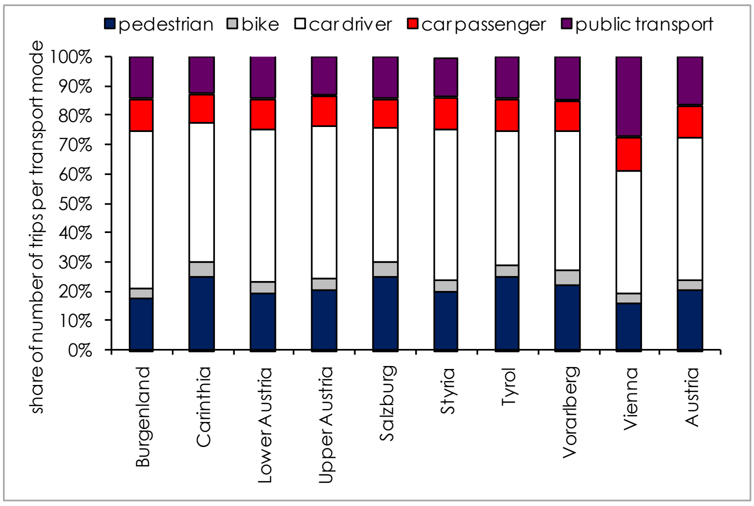
Improvement of public transport	
Increase of the share of public transport	Share of transport performance (pkm) is increased by 3 percentage points by 2020 from 25% (base 2005) to 28% in 2020)
Energy service	4.6 billion pkm are shifted from motorised to public transport by 2020
Technology	Improved public transport
Required capacity increase*	Railway infrastructure, park and ride facilities
Diffusion path	Linear
Total investment	13 billion € by 2020
Total operating costs	581 million € in 2020
Additional operating costs	278 million € in 2020
Emission reduction by wedge*	0.46 million t CO_2 by 2020

* Compared to the reference scenario.

While non-motorised means of transport are competitive with passenger cars for distances within a range of about 2 to 3 km, they are not for longer distances. Therefore the improvement of public transport and the flexible provision of transport options like car sharing and call buses are crucial for enforcing a shift away from motorised transport. The more attractive public transport is the more it will be used and a rethinking and behavioural change can be achieved. Furthermore, the ownership of a car induces (road) transport. There are high fixed costs and low variable costs of car ownership of about 77% to 23% respectively (Statistics Austria, 2002). Fixed costs are usually not anticipated by car owners and therefore only variable costs are compared when the mode choice is made. As is known from many car sharing studies, giving up a car also reduces overall motorised transport performance as car users have to plan and consider each trip they want to make (e.g. TCRP, 2005). Public transport has a lot of advantages compared to individual motorised transport. First, the occupation rate per vehicle is higher, therefore less energy per person is used. Second, in public transport vehicles are driven more frequently than private cars. Cars are used only for about one hour a day on average, therefore occupying a lot of space which causes costs and the occupied space could have been used for other purposes. The reduction potential for CO_2 and other emissions in relation to individual motorised transport due to the enhancement of public transport is higher in densely populated regions.

Modal share of public transport varies in Austria across different federal provinces. The "Transport in Figures" study from BMVIT (BMVIT, 2007) shows shares in the number of trips by mode for Austria and Austrian provinces(Figure 4.8).

Figure 4.8: Regional modal share (number of trips per transport mode)



Source: BMVIT (2007).

On the regional level data for modal share in transport performance are only available with the following restrictions: the base data does not include leisure transport, public electric transport and non-motorised transport. The remainder is categorised into individual motorised transport and public transport. These figures show a share of 20% of the transport performance (passenger kilometres) for public transport in Vienna and lower values for all the other provinces, with e.g. 11% for Styria. If all federal provinces would increase their share of public transport (in passenger kilometres) by 4 percentage points by 2020 (and all starting from a very different level), the overall Austrian share would increase by 3 percentage points by 2020. This target for an increase in public transport is applied to the Austrian database used for calculating the reduction potential of the technology wedge.

Implementation of EnergyTransition methodology for Technology Wedge M-2

In the project EnergyTransition all technology wedges are documented in a common framework as presented in Part B, chapter 3 to ensure their comparability.

For Technology Wedge M-2 (improvement of public transport) the mobility energy service (S) is described by means of passenger kilometres. For the calculation of changes in energy and emissions due to the technology wedge the absolute numbers for an increase in the share of public transport performance by 3 percentage points are calculated for 2020. These passenger kilometres are shifted one-on-one from motorised to public transport (4.6 billion in 2020). So the energy service measured in passenger-km is equal to the reference value in absolute terms. The energy service in this storyline is increasing between 2008 and 2020 by 11% due to the general assumptions (see chapter 4.2.1).

The useful energy intensity u is increasing by 1% compared to 2008. This incorporates the effect coming from the general assumptions of transport development and the shift from motorised to public transport leading to the combined effect on u. Improvements in vehicle efficiency according to the EU regulation on the emission performance standards for new passenger cars as explained in the general assumptions for the storylines are reflected by indicator f. The combination of the two indicators f and u shows the total effect for final energy (F), which is reduced by 9% by 2020 relative to 2008. The figures for changes in service and energy indicators are shown in Table 4.13.

Table 4.13: Technology Wedge M-2: Summary of energy service and energy indicators

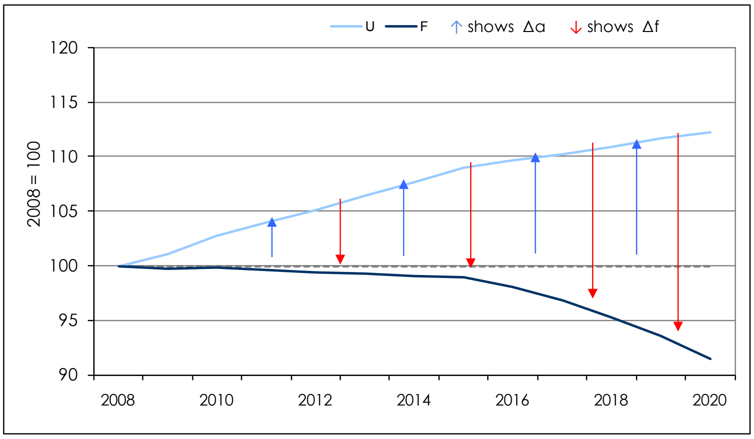
Improvement of public transport	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	11	111
Energy Intensities			
Useful Energy Intensity (u)	100	1	101
Final Energy Intensity (f)	100	-19	81
Final Energy (F)	100	-9	91

Source: Own calculations.

S is increasing as more mobility energy services will be demanded in the future and there is no change but only a shift in providing S – from car to public transport. S for passenger cars increases less than it would have done without Technology Wedge M-2 and public transport increases by about 20% relative to 2008. According to the EnergyTransition methodology changes in useful energy intensity and energy services are given in Δa and changes in final energy intensity are given inΔf. For Technology Wedge M -2 the change due to the increase of S and decrease of u relative to 2008 is summed up in Figure 4.9.

It illustrates changes in final energy demand over time compared to 2008. Δa is positive, because S, mobility demand, and u (useful energy demand per service unit) are increasing over time compared to the base year 2008. Δf expresses the change in final energy demand (F) due to a change in final energy intensity f. These two effects combined lead to a reduction of F by 9% compared to 2008. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.9).

Figure 4.9: Technology Wedge M-2: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity (Δa would increase more without the wedge, as the shift to public transport reduces energy intensity per service unit). Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.14.

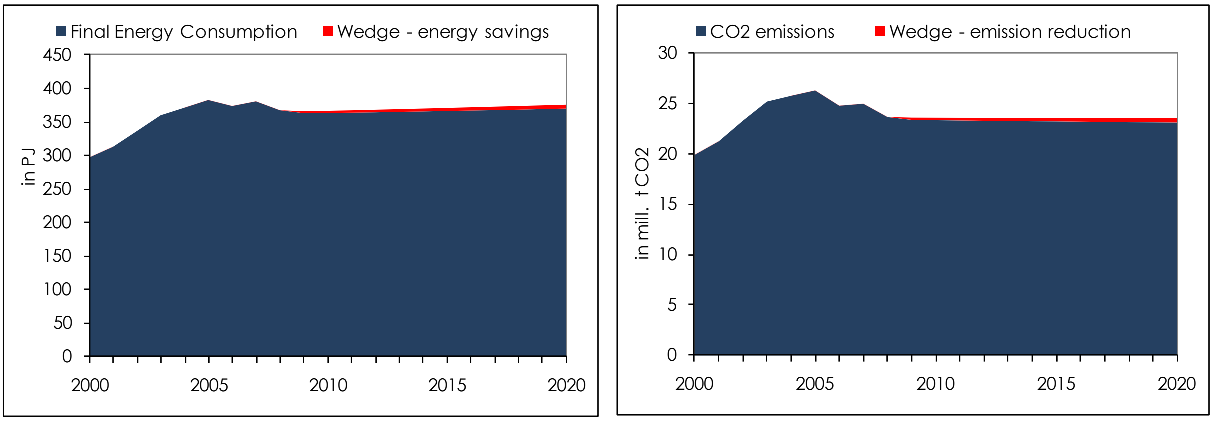
Table 4.14: Technology Wedge M-2: Effects on fuel mix

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.6	87.9
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.2	3.3
Total	100.0	0.0	100.0

Source: Statistics Austria (2009); own calculations.

By applying the target increase of public transport performance of 3 percentage points the overall reduction of motorised transport performance accounts for 4.6 billion pkm by 2020. It is assumed that there is a one-on-one shift from motorised to public transport.

Figure 4.10: Technology Wedge M-2: Effects on energy demand (left) and CO_2 emissions (right)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Final energy decreases by 5.8 PJ by 2020 which is -1.6% relative to the reference scenario. CO_2 emissions are reduced by 2% by 2020. This is 460 kt CO_2 reduced relative to the reference value of 2020 (see Table 4.15 and Figure 4.10).

Table 4.15: Technology Wedge M-2: Effects of on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	324.52	-6.15	-1.9	23.13	22.49	-0.46	-2.0
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.04	-0.30	-1.5	0.00	0.00	0.00	0.0
Electricity	11.56	12.24	0.65	5.3	0.00	0.00	0.00	0.0
Total	366.54	369.01	-5.80	-1.6	23.70	23.16	-0.46	-2.0

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

Studies which show the relation between the change in transport performance by mode and the measures taken to enforce the change are very rare. This is due to the multitude of factors influencing transport behaviour but also due to the lack of recent observed transport data. Therefore investment costs that have to be spent in order to enable an increase by 3 percentage points in the share of public transport performance are deduced from an Austrian study on climate mitigation measures in transport (Steininger et al., 2007). For regional public transport deduced investment costs are 639 million € per year between 2010 and 2020. For the enhancement of rail public transport it is estimated that there has to be additional investment of 458 million € per year between 2010 and 2020. This amount of additional 458 million € per year is added to the investment for regional public transport and accounts for an overall investment of about 1,100 million € per year. Investment in information campaigns and awareness raising are estimated at about 19.4% of the overall investment costs. Investment in rolling stock (trains, locomotives etc.) is summarised in the sector 'other transport equipment' and accounts for 21% of the overall investment. The main share of the investment accrues to the sector construction with 59%; other sectors are metal products and communication equipment considering investment in telematics and marketing. Operating costs are calculated for public rail transport, bus transport and electric regional transport separately and include only variable operating costs (e.g. personnel, energy, maintenance). The operating and maintenance costs for public transport as well as the savings for transport expenditures for private consumers due to reduced car passenger kilometres are netted out in the additional operating costs with 278 million € in 2020. Private transport expenditures decrease by about 290 million € in 2020. External costs or benefits like time costs for drivers or environmental costs are not included within this approach. Private transport expenditures decrease by about 300 million € in 2020 containing fuel, maintenance and other services relating to private vehicle operation.

Table 4.16: Technology Wedge M-2: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Inv estment costs	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097
Additional Costs	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097	1,097
Operating costs	233	262	293	330	348	379	396	436	475	515	541	581
Additional Costs	95	108	122	139	148	163	172	191	212	235	253	278

Source: Steininger et al. (2007); own calculations.

Table 4.17: Technology Wedge M-2: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	59.0	0.0	59.0	0.0
Fabricated metal products, except machinery and equipment	0.23	0.1	0.23	0.1
Printed matter and recorded media	19.4	4.7	19.4	4.7
Other transport equipment	21.2	16.5	21.2	16.5
Radio, television and communication equipment and apparatus	0.16	0.1	0.16	0.1
Total	100.0	21.4	100.0	21.4

Source: Statistics Austria (2010); own calculations.

Operating costs arise from the increase in public transport (maintenance costs and other transport services). Savings in transport expenditures due to the switch from private to public transport occur in cost categories energy, maintenance and operation.

Table 4.18: Technology Wedge M-2: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Maintenance and other transport services (public transport)	100	161
Energy		-51
Maintenance (individual transport)		-6
other services relating to vehicle operation		-4
Total	100	100

Source: Own calculations.

4.2.4 Technology Wedge M-3: Extension of non-motorised transport

The storyline for this technology wedge covers a substitution of passenger kilometres travelled by car by passenger kilometres travelled by bike or pedestrian. The characteristics of the technology wedge are summarised in Table 4.19.

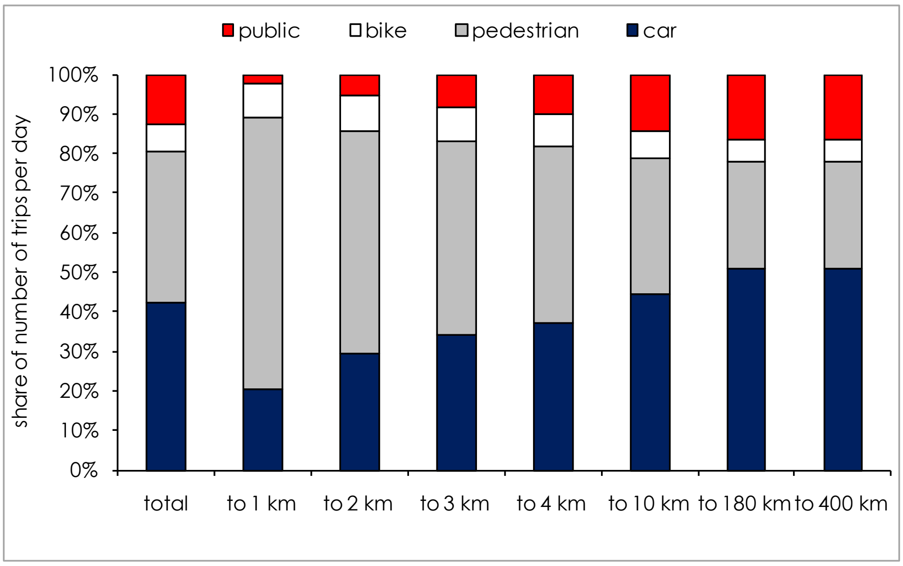
Table 4.19: Summary Table for Technology Wedge M-3

Extension of non-motorised transport	
Energy service	3.6 billion pkm are shifted from motorised to non-motorised transport by 2020
Technology/life style	Behavioural change
Required capacity increase*	300 km bike ways per year.
Diffusion path	Linear
Total investment	648 million € by 2020
Total operating costs	2.2 million € in 2020
Additional operating costs	-238 million € in 2020
Emission reduction *	0.42 million t CO_2 by 2020

* Compared to reference scenario.

Considering all daily trips in Austria the dominant role of passenger cars (42% of all trips) in modal split becomes obvious. The rest is pedestrian with 39%, biking (7%) and public transport (12%). These shares can be further divided by travel distances which show that 20% of all trips within a distance of 1 km or less are made by car (78% of trips within this range are pedestrian or by bike). For the travel distance of up to 2 km 30% of all trips are made by car (drivers and fellow passengers); for the distance of up to 4 km (which is well within the range of an easy doable bike-distance) this share rises up to 37% (Käfer et al., 2009). A considerable potential for emission reductions results from a switch from motorised to non-motorised transport means (i.e. a switch to pedestrian or bike).

Figure 4.11: Share of transport modes by transport distances (number of trips per workday, 2005)



Source: Käfer et al. (2009).

Table 4.20: Share of transport modes for passenger transport by transport distance (number of trips, cumulated shares)

Distance	car	pedestrian	bike	public	total
to 1 km	20%	69%	9%	2%	100%
to 2 km	30%	56%	9%	5%	100%
to 3 km	34%	49%	9%	8%	100%
to 4 km	37%	45%	8%	10%	100%
to 10 km	44%	34%	7%	14%	100%
to 180 km	51%	27%	5%	17%	100%
to 400 km	51%	27%	5%	17%	100%
Total	42%	39%	7%	12%	100%

Source: Käfer et al. (2009).

The figures in Table 4.20 (and Figure 4.11) show that the challenges for the transport sector are to persuade car users not to use the car for destinations that can easily be reached by non-motorised transport means (i.e. to switch to pedestrian or bike).

For the estimation of the technical potential for a switch from car to bike or pedestrian trips different influencing factors have to be considered. First of all the weather plays a major role in the decision, as well as trip purpose, topography, age and physical fitness. For Austria a matrix is defined referring to a Swiss study (INFRAS, 2005) which shows possible combinations of the influencing factors just mentioned and the potential for a shift from motorised to non-motorised transport for each subgroup of the population and respective framework conditions. Four travel purposes are distinguished for the trip chains, as well as three age categories and two different spatial categories, representing the availability of bike and pedestrian infrastructure as well as public transport. The potential is split into four categories: a very high potential (80%), high potential (70%), medium (60%) and low (40%) to switch. The potential for different combinations of factors given in Table 4.21 depicts the main underlying assumptions.

Table 4.21: Technical potential for a switch from motorised to non-motorised transport by different influencing factors

no rain		work/education/personal business			shopping			leisure/business			others		
	trip chains	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.
cities and central districts	0 to 1 km	90%	90%	90%	80%	80%	80%	90%	90%	90%	90%	90%	90%
	1 to 2 km	90%	90%	80%	80%	80%	70%	80%	80%	70%	80%	80%	80%
	2 to 5 km	90%	90%	70%	70%	70%	40%	70%	70%	40%	80%	80%	70%
	5 to 10 km	80%	80%	40%	40%	70%	40%	70%	70%	40%	80%	80%	40%
	10 to 15 km	70%	70%	40%	40%	40%	40%	70%	70%	40%	70%	70%	40%
peripheral districts	0 to 1 km	90%	90%	90%	80%	80%	80%	90%	90%	90%	90%	90%	90%
	1 to 2 km	90%	90%	70%	80%	80%	70%	80%	80%	70%	80%	80%	70%
	2 to 5 km	80%	80%	40%	70%	70%	40%	70%	70%	40%	80%	80%	40%
	5 to 10 km	70%	70%	40%	40%	40%	40%	70%	70%	40%	70%	70%	40%
	10 to 15 km	40%	70%	40%	40%	40%	40%	40%	40%	40%	40%	70%	40%
rain		work/education/personal business			shopping			leisure/business			others		
	trip chains	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.	0-10 y.	11-65 y.	66+ y.
cities and central districts	0 to 1 km	90%	90%	90%	80%	80%	80%	90%	90%	80%	90%	90%	90%
	1 to 2 km	90%	90%	80%	80%	80%	70%	80%	80%	70%	80%	80%	80%
	2 to 5 km	80%	80%	40%	40%	40%	40%	70%	70%	40%	80%	80%	40%
	5 to 10 km	70%	70%	40%	40%	40%	40%	40%	40%	40%	70%	70%	40%
	10 to 15 km	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
peripheral districts	0 to 1 km	90%	90%	80%	80%	80%	80%	80%	80%	80%	90%	90%	90%
	1 to 2 km	80%	90%	70%	70%	80%	70%	80%	80%	70%	80%	80%	80%
	2 to 5 km	70%	80%	40%	40%	40%	40%	70%	70%	40%	70%	70%	40%
	5 to 10 km	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%
	10 to 15 km	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%	40%

Source: Trips by distance and purpose data is based on Herry – Sammer (1999); potential for switch is based on INFRAS (2005); own calculations.

Table 4.21 shows that the potential for a switch is lower for rainy days than for precipitation-free days, at least for trips longer than 2 km. For the calculation of the changes it is assumed that two thirds of all trips are made on days without rain. Potentials also differ depending on different trip purposes, in particular as goods and additional persons cannot be as easily transported by bike or as pedestrians. The potential for trips with purpose "work" and "school" show a higher level than those for "leisure", "personal business" or "shopping". Different topographic conditions and infrastructure supply are considered by different spatial categories. For cities and central districts the switch to bike is more likely than for peripheral districts, as the former generally have better bike lane infrastructure and overall are less hilly. The influence of physical fitness is given by considering different ages. For children (up to 10 years) and older people (66 and older) the potential for a switch for longer distances is much smaller. The potentials are applied on the projected transport performance up to 2020 for calculating the change in transport performance of motorised and non-motorised transport, the change in energy service, intensity and the CO_2 reduction potential. As many measures for non-motorised transport take several years before they have an impact it is assumed that in 2020 only 80% of the given potential is realised.

Implementation of EnergyTransition methodology for Technology Wedge M-3

For the calculation of changes in energy and emissions due to the present technology wedge it is assumed that there is a one-on-one shift from motorised to non-motorised transport performance. So the energy service (S) measured in passenger-km is equal to the reference value in absolute terms. The energy service in this storyline is increasing by 11% between 2008 and 2020. Car transport increases by 10% within this time span, public transport by 3% and non-motorised transport by 152% due to the general assumptions (see chapter 4.2.1) and the shift from motorised to non-motorised transport.

By applying the technical potential for a shift on the projected transport performance of each cell (i.e. the combination of different influencing factors) the overall reduction of motorised transport performance accounts for 3.6 billion pkm by 2020. This amounts to an increase by 3 percentage points in the share of pedestrian and bike in overall transport performance between 2008 and 2020 (i.e. from 2% in 2008 to 5% in 2020).

The useful energy intensity u is increasing by 1% compared to 2008. This incorporates the effect stemming from the general assumptions (increasing u) and the shift from car to bike and pedestrian transport performance (decreasing u). It is assumed that non-motorised transport does not use energy i.e. energy that is relevant for CO_2 emissions which leads to saved energy per pkm. The combined effect expressed by u in this storyline is plus 1%. Improvements in vehicle efficiency according to the EU regulation on the emission performance standards for new passenger cars as explained in the general assumptions are expressed by the indicator f. The combination of the two indicators f and u shows the total effect for final energy (F) which is reduced by 9% by 2020 relative to 2008. The figures for changes in service and energy indicators are shown in Table 4.22.

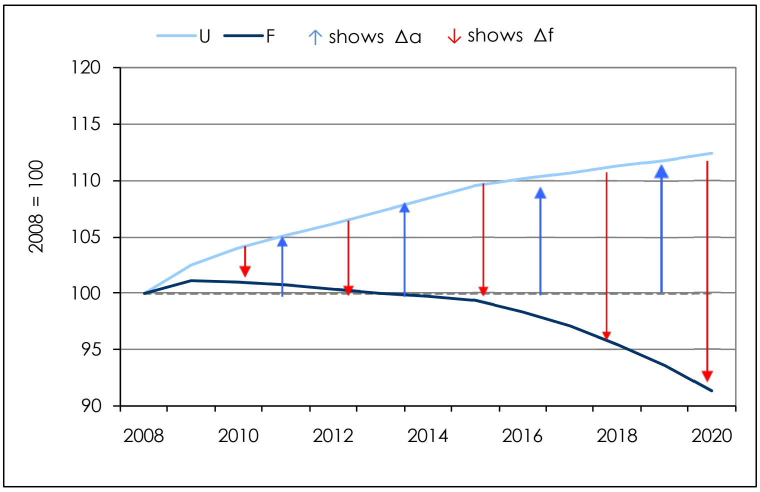
Table 4.22: Technology Wedge M-3: Summary of energy service and energy indicators

Extension of non-motorised transport	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	11	111
Energy Intensities			
Useful Energy Intensity (u)	100	1	101
Final Energy Intensity (f)	100	-19	81
Final Energy (F)	100	-9	91

Source: Own calculations.

S is increasing as more mobility energy service will be demanded in the future compared to 2008 and there is no reduction but only a shift of service demand (S) from car to non-motorised transport. The fraction of S that is provided by the use of passenger cars increases less than it would have done without Technology Wedge M-3 and pedestrian or bike transport performance increase by about 150% relative to 2008. According to the EnergyTransition methodology changes in useful energy intensity and energy services are given in Δa and changes in final energy intensity are given in Δf. For Technology Wedge M-3 the change due to the increase of S and changes of u and f relative to 2008 is summed up in Figure 4.12. It illustrates changes in final energy demand over time compared to 2008. Δa is positive, because S (mobility demand) and u (useful energy demand per service unit) are increasing over time compared to the base year 2008. Δf expresses the change in final energy demand (F) due to a change in final energy intensity f. These two effects combined lead to a reduction of F by 9% compared to 2008. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.12).

Figure 4.12: Technology Wedge M-3: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity (Δa would be higher without the wedge shift to non-motorised transport, as the latter reduces energy intensity). Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.23.

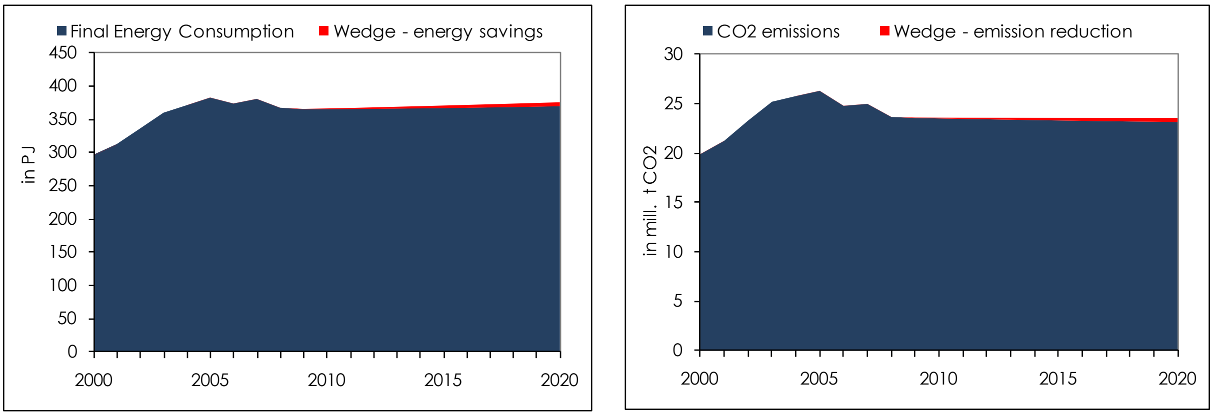
Table 4.23: Technology Wedge M-3: Effects on fuel mix

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.4	88.1
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.0	3.1
Total	100.0	0.0	100.0

Source: Statistics Austria (2009); own calculations.

While the indices show the changes relative to 2008 the following figures show changes relative to the EnergyTransition reference scenario. Final energy decreases by 5.9 PJ (-1.6%) by 2020 and CO_2 emissions are reduced by 420 kt (-1.8%) by 2020 relative to the development path of the reference scenario (see Table 4.24 and Figure 4.13). The reductions occur mainly for energy sources oil and biofuels corresponding to the fuel consumption.

Figure 4.13: Technology Wedge M-3: Effects on energy demand (left) and CO_2 emissions (right)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.24: Technology Wedge M-3: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.0	0.0	0.00	0.00	0.00	0.0
Oil	328.11	325.03	-5.6	-1.7	23.13	22.52	-0.42	-1.8
Gas	10.41	12.20	0.0	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.06	-0.3	-1.4	0.00	0.00	0.00	0.0
Electricity	11.56	11.60	0.0	0.0	0.00	0.00	0.00	0.0
Total	366.54	368.88	-5.9	-1.6	23.70	23.19	-0.42	-1.8

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

In order to tap the full technical potential of the shift from motorised to non-motorised transport pedestrian and bike infrastructure has to be expanded. It is assumed that in Austria bike lanes are extended by at least 300 km per year (2.5% of the overall bike lanes in Austria). The construction costs for bike lanes vary between 90,000 € and 170,000 € per km. Here total costs are calculated with 90.000 € per km. Construction costs for additional footpaths are not included in total investment costs due to a lack of information. Costs for information campaigns, however, include both strategies for bike and pedestrian transport. The investment costs of new bike lanes amount to 54 million € per year whereof 50% accrue in the construction sector. 50% are invested for information campaigns and awareness raising therefore entering the sector "Other business services" especially the marketing and public relation sector and the sector "Printed matter and recorded media". For maintenance of the additional bike lanes about 0.18 million € per year are necessary. Due to the shift from motorised to non-motorised transport private expenditures for transport can be reduced. The average savings from the shift are 245 million € per year. These are mainly expenditures for fuel and repair of vehicles. The additional operating costs include additional maintenance of bike lanes as well as saved expenditures for private consumers (see Table 4.27). Netted out these two effects yield savings of 238 million € in 2020 (see Table 4.25).

Table 4.25: Technology Wedge M-3: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	54	54	54	54	54	54	54	54	54	54	54	54
Additional Costs	54	54	54	54	54	54	54	54	54	54	54	54
Operating costs	0.2	0.4	0.5	0.7	0.9	1.1	1.3	1.4	1.6	1.8	2.0	2.2
Additional Costs	-142	-193	-215	-236	-256	-276	-296	-286	-274	-263	-250	-238

Source: Statistics Austria; own calculations.

Table 4.26: Technology Wedge M-3: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	50	0	50	0
Other business services	30	0	30	0
Printed matter and recorded media	20	4.84	20	4.84
Total	100	4.84	100	4.84

Source: Statistics Austria (2010); own calculations.

Table 4.27: Technology Wedge M-3: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel	0	-91
Maintenance	0	-6
Other services relating to vehicle operation	0	-3
Winter road maintenance and repair	100	0
Total	100	-100

Source: Own calculations.

4.2.5 Technology Wedge M-4: Alternative propulsion technologies

The technology wedge "Alternative propulsion technologies" covers Electric Vehicles (EV) and Plug-in-Hybrid-Vehicles (PHEV). These two technologies will most likely play an important role in the long run to achieve the emission targets in the transport sector. The efficiency of electric vehicles is at least three times higher than that of conventional propulsion systems. However, a widespread deployment of EV und PHEV still faces barriers especially regarding battery technologies. Furthermore, a country-wide system of charging stations has to be installed. Compatibility between possible different (recharging) systems of neighbouring countries may be crucial for a successful market penetration of these technologies within the EU as a whole. Batteries in plug-in vehicles can also be used for electricity storage when there is overcapacity in the grid. The electricity can be redistributed to the grid or to another vehicle at a later point of time.

Concerning the total carbon footprint of EV it has to be mentioned that a predominantly fossil based production of electricity would not improve the GHG emission balance to a significant extent. EVs are only "zero" emission vehicles if the electricity used is produced by respective (renewable) resources (as well as if components are produced in that way). Therefore a promotion of EVs is reasonable if a carbon neutral supply of electricity is ensured. Table 4.28 summarises the characteristics of this technology wedge.

Table 4.28: Summary Table for Technology Wedge M-4

Alternative propulsion technologies	
Substitution of conventional vehicles	93,000 less diesel and 59,000 less gasoline vehicles in 2020
Energy service	1.9 billion pkm are shifted to PHEV and EV in 2020
Technology	PHEV, EV
Required capacity increase*	155,000 PHEV and 55,000 EV in 2020
Diffusion path	Exponential
Total investment	2.3 billion € additional investment costs for EV and PHEV by 2020 (infrastructure costs and additional vehicle costs)
Total operating costs	119 million € by 2020
Operating costs	-33 million € by 2020
Emission reduction*	0.15 million t CO_2 in 2020

* Compared to reference scenario.

Referring to Pötscher et al. (2010) in 2020 about 210,000 EV and PHEV will be on the market. Following the forecast of Hausberger (2010) for the development of the vehicle fleet, this implies a market share of about 4%. The study assumes in the medium-term a share of 25:75 between EV and PHEV considering new registrations, whereby for the next few years producers proclaim a small-scale production predominantly of pure electric vehicles. These assumptions lead to a total amount of about 55,000 EV and 155,000 PHEV in 2020.

In order to calculate the GHG emissions an average annual mileage of 8,000 km for pure EV is assumed. Referring to Parks et al. (2007) PHEV are powered up to 39% by electricity.

Accordingly, the average annual mileage of PHEV is calculated using the mileage of EV and gasoline-driven cars. Regarding the short range of a pure EV we assume that in 60% of the cases EVs substitute gasoline-driven cars, whereas 70% of PHEV substitute diesel-driven cars. The total mileage of EV and PHEV was subtracted from the given mileage of gasoline- and diesel-driven cars using the aforementioned ratio.

Implementation of EnergyTransition methodology for Technology Wedge M-4

Table 4.29 summarises the change of the energy indicators in Technology Wedge M-4. The use of EV and PHEV does not change the estimated transport performance in 2020. This technology wedge implies only a shift from conventional vehicles to EV and PHEV. Therefore, the energy service S is increasing by 11% as it is generally assumed for transport development (see chapter 4.2.1). The useful energy intensity is increasing by 5% due to the general assumptions – first, a general shift in transport mode towards motorised transport, second, a trend towards diesel engines within motorised transport and third, a decreasing occupation rate. Final energy intensity is decreasing by 19%[15] as on the one hand an improvement of efficiency of conventional vehicles is assumed and on the other hand EV and PHEV, which are more efficient than conventional vehicles, are deployed.

Table 4.29: Technology Wedge M-4: Summary of energy service and energy indicators

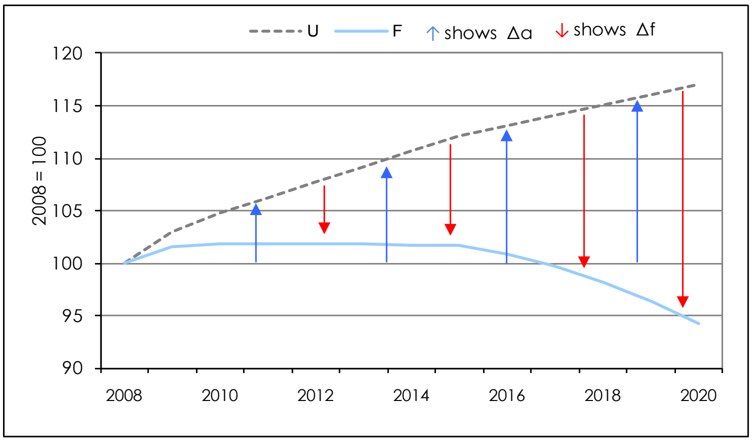
Alternative propulsion technologies	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	11	111
Energy Intensities			
Useful Energy Intensity (u)	100	5	105
Final Energy Intensity (f)	100	-19	81
Final Energy (F)	100	-6	94

Source: Own calculations.

Table 4.29 illustrates the changes in final energy demand over time compared to 2008. Δa expresses the change in S and u. The change is positive, because S and u are increasing over time. Δf expresses the change in final energy intensity f. These two effects combined lead to a reduction of final energy demand F by 6% compared to 2008. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.14).

[15] the value increases from 18.7% (general assumptions) to 19.5% (efficiency increase due to alternative propulsion), after rounding both show as 19% in the table

Figure 4.14: Technology Wedge M-4: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.30.

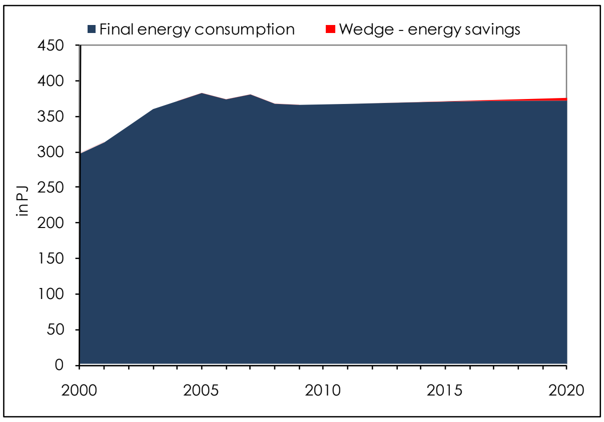
Table 4.30: Technology Wedge M-4: Effects on fuel mix

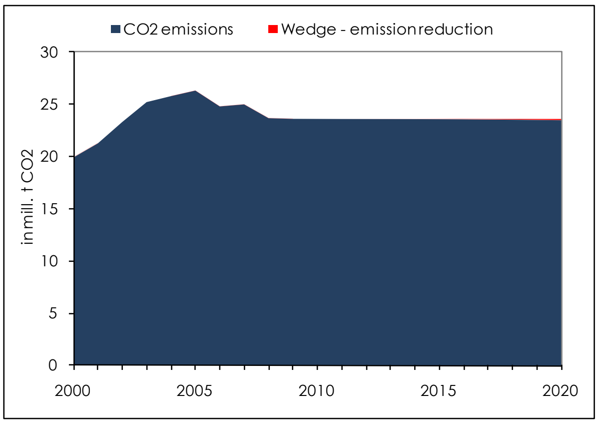
Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.4	88.1
Gas	2.8	0.4	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.1	3.2
Total	100.0	0.0	100.0

Source: Statistics Austria (2009a); own calculations.

Table 4.31 summarises the effects of the implementation of Technology Wedge M-4 on final energy demand and CO_2 emissions in relation to the reference scenario. The effects are also illustrated in Figure 4.15. Final energy is decreasing by 3.8 PJ in 2020. CO_2 emissions are reduced by 0.7% by 2020 relative to the reference scenario.

Figure 4.15: Technology Wedge M-4: Effects on final energy demand and CO_2 emissions





Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.31: Technology Wedge M-4: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	326.70	-3.97	-1.2	23.13	22.79	-0.15	-0.7
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.13	-0.21	-1.0	0.00	0.00	0.00	0.0
Electricity	11.56	11.93	0.33	2.9	0.00	0.00	0.00	0.0
Total	366.54	370.96	-3.84	-1.0	23.70	23.46	-0.15	-0.7

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

EV and PHEV are still considerably more expensive than conventional vehicles. The main driver of the vehicle costs are the batteries. The additional investment costs of EV and PHEV are calculated using data from Haas et al. (2009). In 2010 the average price of an EV is about 48,000 €, of a PHEV about 26,000 €. The price of a conventional vehicle is taken at an average of 15,000 €. For the mid- to long-term development of the costs of batteries Haas et al. (2009) applied the concept of technological learning. Improvements in production, mass production and technological development will lead to a reduction of costs, following an exponential function. Thus, in 2020 the costs are reduced to 29,000 € for an EV and 21,000 € for a PHEV. The prices of conventional vehicles are assumed to remain constant (in real terms). This leads to total additional investment costs for vehicles of about 1.8 billion € by 2020.

The use of EV and PHEV needs an area-wide installation of charging stations, both in private and public areas. Zoglauer et al. (2010) assessed the costs of a charging station between 500 and 4,000 €. In order to calculate the total investment costs we used the average value of 2,250 € per charging station. The equipment of all service stations in Austria with a charging station for EV and PHEV and in addition one charging station for each EV and PHEV in the private area will lead to total investment costs for infrastructure of 477 million € by 2020. In total the additional investment costs amount to 2.3 billion € by 2020.

The use of EV and PHEV as estimated leads to operating costs for electricity and fuel of about 119 million € in 2020 (calculated with energy prices of the year 2008). In total, operating costs can be reduced by about 33 million € in 2020, when the lower demand for gasoline and diesel and the additional expenses for electricity are netted out.

Table 4.32 shows the development of investment costs and operating costs. In Table 4.33 the investment costs are apportioned to the involved economic sectors. It is assumed that one third of the costs of charging stations arise due to construction work and two thirds result from electrical machinery and apparatus. In total 79.3% of the additional investment costs are vehicle costs. Table 4.34 shows the split of operating costs into saved fuel expenses and additional electricity costs.

Table 4.32: Technology Wedge M-4: Development of investment costs and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	0	18	43	68	74	97	301	458	722	979	1,244	1,430
Additional Costs	0	13	28	42	34	43	131	196	305	408	513	583
Operating costs	0	0	0	1	3	5	12	23	40	62	89	119
Additional Costs	0	0	-1	-1	-2	-2	-4	-8	-12	-18	-26	-33

Source: Haas et al. (2009), Zoglauer et al. (2010), Statistics Austria (2006); own calculations.

Table 4.33: Technology Wedge M-4: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	2.9	0.0	6.9	0.0
Electrical machinery and apparatus	5.8	1.7	13.8	4.1
Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel	91.2	54.7	79.3	47.6
Total	100.0	56.5	100.0	51.6

Source: Statistics Austria (2010); own calculations. – The import share of 60% in the sector trade is conform to the import content of durable consumer goods.

Table 4.34: Technology Wedge M-4: Disaggregation of operating costs

Category	Av erage share in total operating costs in %	Av erage share in additional oc in %
Fuel	64	-219
Electricity	36	119
Total	100	-100

Source: Own calculations.

Cost appraisal

In addition to the depiction of total investment and operating costs the effects of wedge M-4 are expressed by user costs of capital i.e. costs per unit activity (e.g. vehicle kilometres) considering the estimated service life and interest rate of capital. The calculated user cost of capital are added up with the energy costs per unit activity. Total costs for the new technology are then contrasted to total costs of the reference technology in order to calculate additional costs per unit activity. Within wedge M-4 two different technologies are considered which are electric vehicles (EV) and Plug-in Electric Vehicles (PHEV). For both, additional costs are calculated by comparing them to the reference technology. The reference technology is the average car (conventional combustion engine) in the Austrian fleet with an average mileage, average specific fuel consumption and average investment and operating costs. For the average mileage of electric vehicles 8,000 vehicle kilometres are assumed per year and compared with a conventional driven vehicle with the same mileage. Vehicles that are used for short distances are more likely to be replaced by electric vehicles. The investment price for electric vehicles is 60 €cent/vkm in 2009 decreasing to 36 €cent/vkm in 2020 which is about 2 times higher than prices for conventional vehicles per vkm in 2020. The price difference for the investment costs of the two different technologies is mainly due to high battery costs. For conventional vehicles the energy use (kWh/vkm) is 2.4 times higher than for electric vehicles in 2020. For the calculation of the energy costs for the average conventional vehicle (standard technology) we use energy prices for gasoline and diesel and multiply them with the energy use for these two different drives. As it is assumed in the general assumptions of the storylines that there is an increasing percentage of gasoline engines in the Austrian fleet until 2020 and gasoline prices are higher than diesel prices, the energy cost for the average vehicle is (slightly) higher in 2020 than in 2009. Although energy prices per kWh are higher for electric vehicles than for the standard technology (Statistics Austria, 2008) energy costs per vkm are smaller for electric vehicles due to the strong increase in energy efficiency. The energy savings are about 5 €cent/vkm in 2009 and 3 €cent/vkm in 2020 (see Table 4.35).

The additional cost per vkm for electric vehicles compared to a standard technology (with average mileage of 8,000 vkm p.a.) are calculated by comparing total costs for the two technologies i.e. the sum of user costs per capital and energy costs. For 2009 the additional costs are 0.4 €cent/vkm for 2020 the difference to conventional drives is only minus 1 €cent/vkm (that is electric vehicles pay off in 2020).

The same calculation is done for the interest rate of 5% showing that additional costs are 1.4 €cent/vkm in 2009 and there are savings in 2020 of 0.5 €cent/vkm.

Table 4.35: Additional cost of electric vehicles 2009 and 2020 (assumed interest rate 2.5%)

Electric Vehicle		**2009**	**2020**
Unit Activity	vehicle km		
Investments			
Service life	years	10	10
Interest rate	% p.a.	2.5	2.5
Investment cost standard	€ct/vkm	18.75	18.75
Investment cost electric	€ct/vkm	60.00	36.42
User cost of capital standard	*€ct/vkm p.a.*	2.34	2.34
User cost of capital electric	*€ct/vkm p.a.*	*7.50*	*4.55*
User cost of capital additional	***€ct/vkm p.a.***	***5.16***	***2.21***
Operating			
Energy flow standard	kWh/vkm	0.64	0.52
Energy flow electric	kWh/vkm	0.21	0.21
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) electric	€ct/kWh	18.00	18.00
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost electric	*€ct/vkm p.a.*	*3.78*	*3.78*
Energy cost savings	***€ct/vkm p.a.***	***4.70***	***3.16***
Total			
Total cost standard	*€ct/vkm p.a.*	*10.83*	*9.28*
Total cost electric	*€ct/vkm p.a.*	*11.28*	*8.33*
Additional cost	***€ct/vkm p.a.***	***0.45***	***-0.95***

Source: Own calculations.

Table 4.36: Additional cost of electric vehicles 2009 and 2020 (assumed interest rate 5%)

Electric Vehicle		**2009**	**2020**
Unit Activity	vehicle km		
Investments			
Service life	years	10	10
Interest rate	% p.a.	5.0	5.0
Investment cost standard	€ct/v km	18.75	18.75
Investment cost electric	€ct/v km	60.00	36.42
User cost of capital standard	*€ct/vkm p.a.*	2.81	2.81
User cost of capital electric	*€ct/vkm p.a.*	*9.00*	*5.46*
User cost of capital additional	***€ct/vkm p.a.***	***6.19***	***2.65***
Operating			
Energy flow standard	kWh/v km	0.64	0.52
Energy flow electric	kWh/v km	0.21	0.21
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) electric	€ct/kWh	18.00	18.00
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost electric	*€ct/vkm p.a.*	*3.78*	*3.78*
Energy cost savings	***€ct/vkm p.a.***	***4.70***	***3.16***
Total			
Total cost standard	*€ct/vkm p.a.*	*11.30*	*9.75*
Total cost electric	*€ct/vkm p.a.*	*12.78*	*9.24*
Additional cost	***€ct/vkm p.a.***	***1.48***	***-0.51***

Source: Own calculations.

The additional costs have been calculated in the same way for PHEVs as well as with an interest rate 2.5% and 5% respectively. The average mileage for PHEVs is assumed to be the same as the standard technology with about 14,650 kilometres per year in 2009 and 14,200 in 2020. Investment costs per vkm and user cost of capital are about 1.5 times higher in 2020 for PHEVs (Haas et al. 2009). The energy use for PHEvs is about 75% of the standard technology (2020). Energy prices are slightly higher for PHEVs than for the standard technology leading to a difference of energy costs of about 1 €cent/vkm in 2020. The additional costs for an interest rate of 2.5% are minus 0.5 €cent/vkm for 2009 and minus 0.7 €cent/vkm for 2020. For an interest rate of 5% the additional costs for 2009 are minus 0.3 €cent/vkm and minus 0.5 €cent/vkm for 2020 showing an advantage of PHEVs compared to the standard technology (see Table 4.37 and Table 4.38).

Table 4.37: Additional cost of a PHEV 2009 and 2020 (assumed interest rate 2.5%)

PHEV		2009	2020
Unit Activity	vehicle km		
Investments			
Service life	years	10	10
Interest rate	% p.a.	2.5	2.5
Investment cost standard	€ct/vkm	10.23	10.56
Investment cost PHEV	€ct/vkm	17.74	14.83
User cost of capital standard	*€ct/vkm p.a.*	1.28	1.32
User cost of capital PHEV	*€ct/vkm p.a.*	2.22	1.85
User cost of capital additional	***€ct/vkm p.a.***	***0.94***	***0.53***
Operating			
Energy flow standard	kWh/vkm	0.64	0.52
Energy flow PHEV	kWh/vkm	0.49	0.39
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) PHEV	€ct/kWh	14.39	14.90
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost PHEV	*€ct/vkm p.a.*	*7.07*	*5.79*
Energy cost savings	***€ct/vkm p.a.***	**1.41**	**1.15**
Total			
Total cost standard	*€ct/vkm p.a.*	*9.76*	*8.26*
Total cost PHEV	*€ct/vkm p.a.*	*9.29*	*7.64*
Additional cost	***€ct/vkm p.a.***	***-0.48***	***-0.61***

Source: Own calculations.

Table 4.38: Additional cost of a PHEV 2009 and 2020 (assumed interest rate 5%)

PHEV		2009	2020
Unit Activity	vehicle km		
Investments			
Service life	years	10	10
Interest rate	% p.a.	5.0	5.0
Investment cost standard	€ct/vkm	10.23	10.56
Investment cost PHEV	€ct/vkm	17.74	14.83
User cost of capital standard	*€ct/vkm p.a.*	1.54	1.58
User cost of capital PHEV	*€ct/vkm p.a.*	2.66	2.22
User cost of capital additional	***€ct/vkm p.a.***	***1.13***	***0.64***
Operating			
Energy flow standard	kWh/vkm	0.64	0.52
Energy flow PHEV	kWh/vkm	0.49	0.39
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) PHEV	€ct/kWh	14.39	14.90
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost PHEV	*€ct/vkm p.a.*	*7.07*	*5.79*
Energy cost savings	***€ct/vkm p.a.***	**1.41**	**1.15**
Total			
Total cost standard	*€ct/vkm p.a.*	*10.02*	*8.52*
Total cost PHEV	*€ct/vkm p.a.*	*9.73*	*8.01*
Additional cost	***€ct/vkm p.a.***	***-0.29***	***-0.51***

Source: Own calculations.

4.2.6 Technology Wedge M-5: Freight transport

The storyline for this technology wedge covers the promotion of intermodal transport and improvement of logistic systems using teleinformatics in transport. The characteristics of the technology wedge are summarised in Table 4.39.

Table 4.39: Summary Table for Technology Wedge M-5

Freight transport	
Energy Service	Reduction of 5.96 b. t-km by roads and an increase of 3.69 b. t-km by rail in 2020
Technology	Improved intermodal transport, logistics and teleinformatics of transport
Required capacity increase*	Not available
Diffusion path	Linear
Total investment	258 million € by 2020
Operating costs	Not available
Emission reduction*	0.4 million t CO_2 in 2020

*Compared to reference scenario.

The emission reduction potential of freight transport compared to a reference development, in particular the potential of shifting transport from road to rail, is based on Kapfer et al. (2005). This study covers measures in logistics, teleinformatics in transport and intermodal transport. Until 2015 a yearly emission reduction potential in road transport of about 12% can be achieved. The smaller absolute increase in rail tkm amounts to an increase of rail transport by 17%. We assume a linear increase to reach this energy and emission reduction potential until 2015.

Implementation of EnergyTransition methodology for Technology Wedge M-5

Table 4.35 summarises the change of the energy indicators in Technology Wedge M-5. These indicators refer to transport performance and energy demand of freight transport only. The energy service (S) is increasing by 12%, which reflects the general assumptions of the development of S and in addition the reduction in transport performance due to efficiency enhancement in the technology wedge (without the efficiency increase by the wedge the increase in S would be 15%). The useful energy intensity (u) is decreasing by 10% due to a shift of freight transport from road to the less energy intensive transport by rail and an increase of the loading rate as generally assumed in chapter 4.2.1. Final energy intensity is decreasing by 1% as an improvement of truck efficiency is assumed.

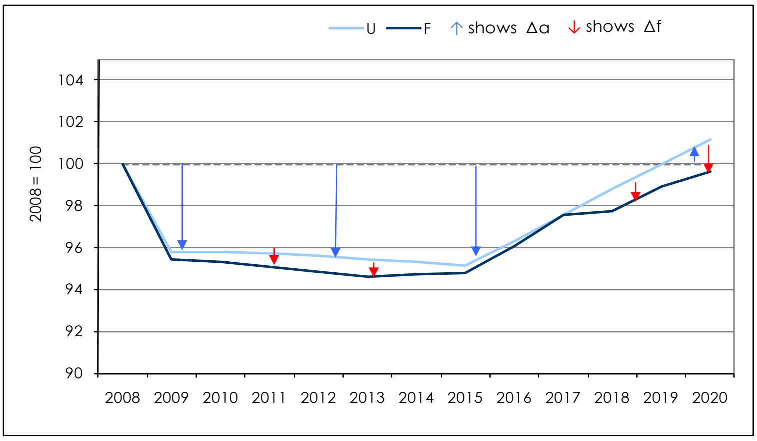
Table 4.40: Technology Wedge M5: Summary of energy service and energy indicators

Freight transport	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	12	112
Energy Intensities			
Useful Energy Intensity (u)	100	-10	90
Final Energy Intensity (f)	100	-1	99
Final Energy (F)	100	0	100

Source: Own calculations.

Figure 4.16 illustrates the changes in final energy demand over time compared to 2008. Δa expresses the change in S and u (useful energy intensity) and is indicated by the light blue arrows. In 2009 a drop in transport performance is given based on data from Hausberger (2010) and reflecting the most recent development. Until 2015 yearly emission reduction in road transport is assumed to reach 12% compared to a reference path (which is the full potential), thereafter yearly emission reduction stays at this level. As a consequence of increasing transport performance, but now stable emission reduction rates, the path of final energy demand is increasing again. We therefore use a conservative scenario here. One might assume alternatively that the efficiency increase continues up to 2020. In our scenario, in total the effect of a decrease in useful energy intensity on final energy demand is almost compensated by the increase in S over time compared to 2008. Δf expresses the change in final energy (F) due to a change in final energy intensity f and is indicated by the red arrows in Figure 4.16 The share of gasoline driven trucks is declining under our general assumptions, and is substituted by less emission intensive diesel trucks. This development is assumed to be completed in 2018 when there are no more gasoline driven trucks to be substituted, which is apparent in Figure 4.16. As shown in Table 4.40 the change in f (final energy intensity) over time is small. Hence, final energy demand in freight transport does not decrease below the level of 2008.

Figure 4.16: Technology Wedge M5: Effects on useful energy and final energy[1]



Source: Own illustrations. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.41.

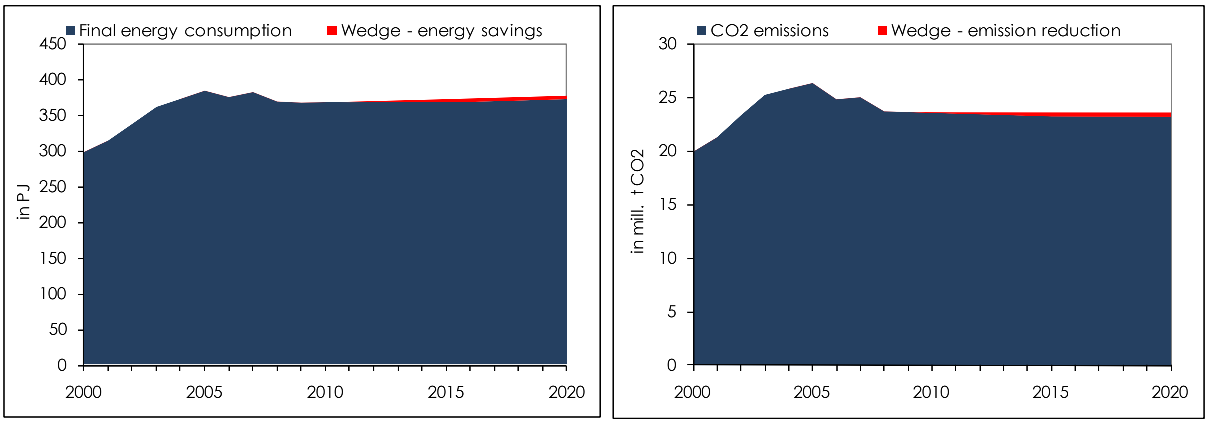
Table 4.41: Technology Wedge M-5: Effects on fuel mix

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.6	87.9
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.2	3.4
Total	100.0	0.0	100.0

Source: Statistics Austria (2009a); own calculations.

Table 4.42 summarises the effects of the implementation of Technology Wedge M-5 on final energy demand and CO_2 emissions in relation to the reference scenario. The effects are also illustrated in Figure 4.17. 1.3% of final energy and accordingly 400 kt CO_2 can be reduced in 2020.

Figure 4.17: Technology Wedge M-5: Effects on final energy and CO_2 emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.42: Technology Wedge M-5: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	325.22	-5.44	-1.6	23.13	22.54	-0.40	-1.7
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.01	-0.33	-1.6	0.00	0.00	0.00	0.0
Electricity	11.56	12.43	0.83	7.2	0.00	0.00	0.00	0.0
Total	366.54	369.86	-4.95	-1.3	23.70	23.22	-0.40	-1.7

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

The data for the investment costs are based on the National Allocation Plan for Austria (BMLFUW, 2004). The funding program focuses on the shift of transport from road to rail. It is assumed that the funding programs for intermodal transport and industrial siding tracks, which terminate in 2014 and 2012 respectively, are continued until 2020. A funding volume of 2.9 million € is provided yearly for measures of intermodal transport and 9.5 million € for industrial siding tracks. With the programs only 30% and 40% respectively of the total investment costs can be funded. In order to calculate total investment costs we assume that the capacity of funding is fully used. Hence, the total investment costs amount to 255 million € by 2020. Operating costs could not be determined for this study. Table 4.43 and Table 4.44 show the investment costs for each year and disaggregated to the economic sectors.

Table 4.43: Technology Wedge M-5: Development of investment and operating costs (million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	33	33	33	33	33	33	33	33	33	33	33	33
Additional Costs	33	33	33	33	33	33	33	33	33	33	33	33
Operating costs	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Additional Costs	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Source: Own calculations based on BMLFUW (2004). – n.a. is not available.

Table 4.44: Technology Wedge M-5: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	71	0	71	0
Machinery and equipment n.e.c.	6	2	6	2
Motor vehicles, trailers and semi-trailers	9	3	9	3
Other transport equipment	9	5	9	5
Computer and related services	4	0	4	0
Other business services	1	0	1	0
Total	100	11	100	11

Source: Statistics Austria (2010); own calculations.

4.2.7 Technology Wedge M- 6: Efficiency increase by lightweight construction of vehicles

Among various possibilities to reduce the fuel consumption of vehicles, lightweight constructions can contribute significantly to improved fuel economy. The share of light materials used for cars has been continuously increasing. While in 1975 a conventional car consisted of about 39 vol.% steel, 23 vol.% plastics and 6 vol.% aluminium, in 2005 the relative importance of materials for cars changed to about 20 vol.% steel, 44 vol.% plastics and 11 vol.% aluminium (IVW Kaiserslautern, 2009). That the materials choice has a significant impact on resource efficiency was shown by Pilz et al. (2005) using a projection based method. Considering the total life cycle energy demand and the total greenhouse gas emissions in terms of CO_2e for automotive applications, plastic product solutions were compared with the next best alternative product solution based on metals, wood, glass, etc. A main result of this study was that the plastics based product solutions for automobiles need 25% less energy and reduce CO_2 emissions by 34%.

Despite the fact that the share of light materials has been increasing over the last 3 decades, there was also an increase in the overall car weight by about 50 to 70% (from 1975 to 2005). Hence, current strategies in lightweight design of cars focus on the reversal of the weight spiral. Recent studies provide clear evidence that there is still a huge potential to improve the fuel economy of vehicles by lightweight constructions (e.g. www.superlightcar.com). While up to 35% of weight reduction will be achievable by replacement of selected components with optimised parts based on light materials and material hybrids, a transition to ultra-lightweight vehicles allowing for higher weight reductions requires a complete redesign of vehicles. This includes the utilisation of advanced lightweight construction principles currently applied for example in the sports and leisure industry (e.g., composite bicycles, race cars) or in the aviation industry), on the one hand, and a fundamental redesign of the whole vehicle including the engine concept and the power train, on the other.

For this technology wedge we assume an energy efficiency increase of 5% until 2020, which requires a vehicle mass reduction of about 20% (Hausberger, 2010; personal communication). To achieve this mass reduction light-weight materials and multi-material construction principles (hybrid materials concepts) have to be applied for the car body, the chassis, the power train and the interior. While for the chassis and the power train light metals are of prime importance, in the car body and the interior hybrid materials mainly based on plastics are of special relevance.

Table 4.45: Summary Table for Technology Wedge M-6

Efficiency increase by lightweight construction of vehicles	
Energy service	No change in transport performance
Technology	Lightweight construction of vehicles
Required capacity increase*	5% efficiency increase by 2020
Diffusion path	Linear
Operating costs	-261 million € in 2020
Emission reduction*	0.5 million t CO_2 in 2020

* Compared to reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge M-6

Table 4.46 summarises the change of the energy indicators in Technology Wedge M-6. The development of energy service (S) and useful energy intensity (u) follows the same path as in Technology Wedge M-4. More efficient vehicle technologies do not change the estimated transport performance in 2020. The energy service S is increasing by 11% as it is generally assumed for transport development. The useful energy intensity is increasing by 5% due to the general assumptions underlying all the storylines (see chapter 4.2.1). Both, the additional efficiency increase by lightweight construction of vehicles and the efficiency increase already assumed in all the storylines, is reflected in final energy intensity f, which is decreasing by 22% in 2020 compared to 2008. Light weight components are only considered in cars not in public transport vehicles which leads to an overall increase of energy intensity of 3% (compared to 19% increase between 2008 and 2020 under the general assumptions).

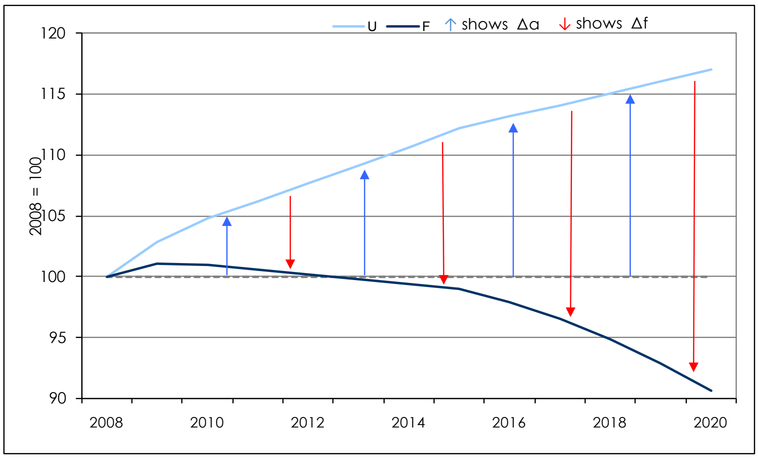
Table 4.46: Technology Wedge M-6: Summary of energy service and energy indicators

Efficiency increase by light-weight construction of vehicles	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	11	111
Energy Intensities			
Useful Energy Intensity (u)	100	5	105
Final Energy Intensity (f)	100	-22	78
Final Energy (F)	100	-9	91

Source: Own calculations.

Figure 4.18 illustrates the changes in final energy demand over time compared to 2008. Δa expresses the change in S and u as described above. Δf expresses the change in final energy demand (F) due to a change in final energy intensity f. The reduction of final energy demand compared to 2008 due to an efficiency increase is partly compensated by the increase in energy service and useful energy intensity depicted in Δa. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.18).

Figure 4.18: Technology Wedge M-6: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.47.

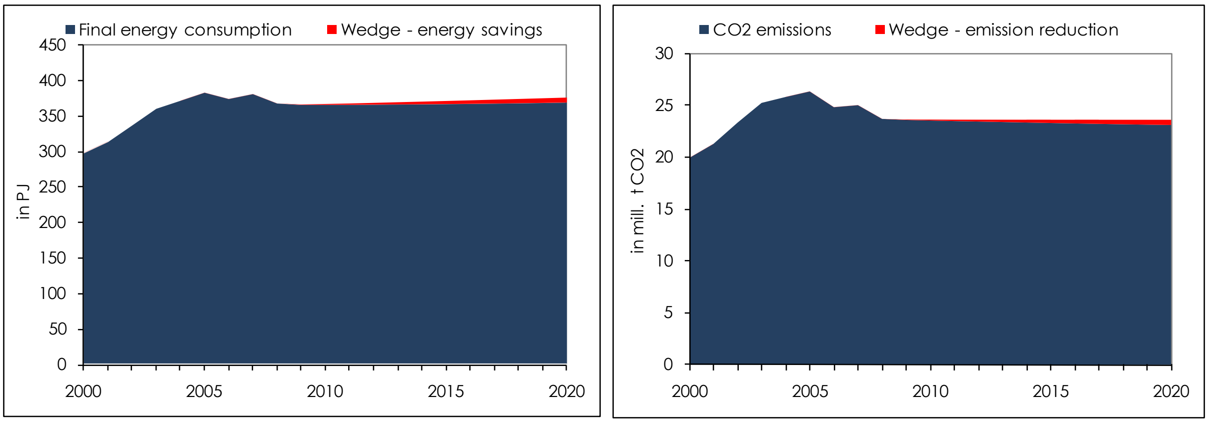
Table 4.47: Technology Wedge M-6: Effects on fuel mix

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.4	88.1
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.0	3.2
Total	100.0	0.0	100.0

Source: Statistics Austria (2009a); own calculations.

Table 4.48 and Figure 4.19 show the effects of the implementation of Technology Wedge M-6 on final energy demand and CO_2 emissions in relation to the reference scenario. 1.9% of final energy demand and accordingly about 500 kt CO_2 can be reduced in 2020 compared to a reference path without an additional efficiency increase.

Figure 4.19: Technology Wedge M-6: Effects on final energy demand and CO_2 emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.48: Technology Wedge M-6: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	323.94	-6.73	-2.0	23.13	22.44	-0.50	-2.2
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.00	-0.34	-1.7	0.00	0.00	0.00	0.0
Electricity	11.56	11.60	0.00	0.0	0.00	0.00	0.00	0.0
Total	366.54	367.75	-7.06	-1.9	23.70	23.11	-0.50	-2.1

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

As the automotive sector is under pressure currently new technologies will only prevail when they are competitive with technologies used so far. Depending on the price of currently used raw materials light constructions materials will be competitive. Therefore we assume that there are no additional investment costs for the 20% weight reduction (for a reduction of 35% of the vehicle mass about 5 € per kg saved weight are assumed by the European project SuperLIGHT-Car (www.superlightcar.com)). Because no change in investment costs is assumed, total investment costs, as shown in Table 4.49, are calculated using data from the Household Budget Survey (Statistics Austria 2006) concerning yearly expenditures for vehicles of all Austrian households. The development of investment costs follows the underlying assumptions of the vehicle fleet by 2020 in our reference scenario. Investment costs and total operating costs mirror the assumption that in 2020 all new bought cars are lightweight. Due to the mass reduction and hence efficiency gains transport expenditures on fuel decrease by 261 million € in 2020 (see Table 4.50).

Table 4.49: Technology Wedge M-6: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	1,869	1,916	1,995	2,110	2,266	2,471	2,736	3,067	3,482	4,003	4,659	5,488
Additional Costs	0	0	0	0	0	0	0	0	0	0	0	0
Operating costs	434	875	1,316	1,759	2,203	2,647	3,092	3,514	3,915	4,291	4,639	4,956
Additional Costs	-23	-46	-69	-93	-116	-139	-163	-185	-206	-226	-244	-261

Source: Statistics Austria, own calculations. – The investment figures assume for 2020 that all new bought vehicles are lightweight. This is also shown in total operating costs, where total expenditures for fuels in 2020 accrue to lightweight vehicles.

Table 4.50: Technology Wedge M-6: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel	0	-100
Total	0	-100

Source: Own calculations.

Cost appraisal

As in chapter 4.2.5 for electric and Plug-in electric vehicles the method for calculating additional costs per unit activity (vkm) is applied for vehicles with light weight components to increase efficiency. It is assumed for the construction of vehicles with light weight components that there are no additional costs as the automobile industry is under pressure and will only assemble the new components if there is no increase of investment costs. Investment costs are the same for standard and light weight vehicles entering total costs equally. The additional costs per vkm are the same for different interest rates (2.5 and 5%) as the change in total costs only occurs due to the increase in energy efficiency by 5% for light weight vehicles compared to conventional drives. Energy costs thus decrease due to efficiency gains by 5%. The additional costs are minus 0.42 €cent/vkm in 2009 and minus 0.35 €cent/vkm in 2020 for alternative interest rates of 2.5% and 5% respectively (see Table 4.51 and Table 4.52). The value for 2020 is lower than that of 2009 as our baseline assumption of a general efficiency increase does hold here as well, causing the 5% energy efficiency increase to amount to a smaller absolute value in 2020. As cost changes concern operating costs only (and no investment components), the choice of the interest rate does not change results for NPV (net present value) of absolute costs saved per km here.

Table 4.51: Additional cost of a light weight vehicle 2009 and 2020 (assumed interest rate 2.5%)

Leight weight vehicle		**2009**	**2020**
Unit Activ ity	v ehicle km		
Investments			
Serv ice life	years	10	10
Interest rate	% p.a.	2.5	2.5
Inv estment cost standard	€ct/v km	10.23	10.56
Inv estment cost leight weight	€ct/v km	10.23	10.56
User cost of capital standard	*€ct/vkm p.a.*	1.28	1.32
User cost of capital leight weight	*€ct/vkm p.a.*	1.28	1.32
User cost of capital additional	***€ct/vkm p.a.***	***0.00***	***0.00***
Operating			
Energy flow standard	kWh/v km	0.64	0.52
Energy flow leight weight	kWh/v km	0.61	0.50
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) leight weight	€ct/kWh	13.24	13.30
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost leight weight	*€ct/vkm p.a.*	*8.06*	*6.59*
Energy cost savings	***€ct/vkm p.a.***	***0.42***	***0.35***
Total			
Total cost standard	*€ct/vkm p.a.*	*9.76*	*8.26*
Total cost leight weight	*€ct/vkm p.a.*	*9.34*	*7.91*
Additional cost	***€ct/vkm p.a.***	***-0.42***	***-0.35***

Source: Own calculations.

Table 4.52: Additional cost of a light weight vehicle 2009 and 2020 (assumed interest rate 5%)

Leight weight vehicle		**2009**	**2020**
Unit Activity	vehicle km		
Investments			
Service life	years	10	10
Interest rate	% p.a.	5.0	5.0
Investment cost standard	€ct/vkm	10.23	10.56
Investment cost leight weight	€ct/vkm	10.23	10.56
User cost of capital standard	*€ct/vkm p.a.*	1.54	1.58
User cost of capital leight weight	*€ct/vkm p.a.*	1.54	1.58
User cost of capital additional	***€ct/vkm p.a.***	***0.00***	***0.00***
Operating			
Energy flow standard	kWh/vkm	0.64	0.52
Energy flow leight weight	kWh/vkm	0.61	0.50
Energy price (mix) standard	€ct/kWh	13.24	13.30
Energy price (mix) leight weight	€ct/kWh	13.24	13.30
Energy cost standard	*€ct/vkm p.a.*	*8.48*	*6.94*
Energy cost leight weight	*€ct/vkm p.a.*	*8.06*	*6.59*
Energy cost savings	***€ct/vkm p.a.***	***0.42***	***0.35***
Total			
Total cost standard	*€ct/vkm p.a.*	*10.02*	*8.52*
Total cost leight weight	*€ct/vkm p.a.*	*9.59*	*8.17*
Additional cost	***€ct/vkm p.a.***	***-0.42***	***-0.35***

Source: Own calculations.

4.2.8 Technology Wedge M-7: Increase of biofuel additions

The storyline for this technology wedge covers an increase of the additions of biofuels. The characteristics of the technology wedge are summarised in Table 4.53.

Table 4.53: Summary Table for Technology Wedge M-7

Increase of biofuels additions	
Energy service	Constant relative to reference
Technology	Improved biofuel synthesis
Required capacity increase*	None
Diffusion path	Linear interpolation between target values
Total investment	0
Total operating costs	95 million € in 2020
Additional operating costs	95 million € in 2020
Emission reduction by wedge*	0.6 million t CO_2 in 2020

* Compared to the reference scenario.

The aim of the Austrian biofuel act of 2004 is a biofuel addition of 5.75% of the overall fuel sold in Austria. Since October 1st 2005 there is an obligation to replace 2.5% (of the energy content) of all gasoline and diesel fuels placed on the market by biofuels. Since October 1st 2007 this share has increased up to 4.3% and since October 1st 2008 it is 5.75%.

The Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport includes an increase of the share of biofuels of 5.75% up to 2010 (European Parliament and the Council, 2003). The directive was replaced by the directive on the promotion of the use of energy from renewable sources which includes the 20% target for the share of renewable energy sources measured in terms of total energy use of the EU by 2020. Furthermore there is an obligatory target for the share of alternative fuels in overall gasoline and diesel fuel consumption of 10% until 2020. From the EU Green Paper on the security of energy supply COM(2000)769 the following target values can be derived: 7% until 2015, 10% until 2020 and 25% until 2030 (European Commission, 2003).

There is growing interest in biofuels as renewable sources to be used for combustion engines. While biofuel demand is growing the conflict between agricultural products for nutrition and bioenergy is rising. New technologies produce biofuels from wood which is not in conflict with food production. There are plans for demo plants to produce biofuels from wood in Austria.

Biofuels of the 1st and 2nd generation are distinguished. Biofuels of the first generation are biodiesel from oilseed (sunflowers, raps and soya) and bioethanol from sugar plants or starch. They are used as biofuels at the moment. Biofuels of the second generation are for instance bioethanol made from wood. This is crucial as wood is not competing for land with food. There are several pilot projects for it in Austria.

For the calculation of the reduction potential of the wedge only biofuels of the first generation are considered here. The increase of the biofuel share was calculated following the trend scenario for Austria done by UBA and BMLFUW up to 2030 (Molitor et al., 2009)(see Table 4.54).

Table 4.54: Technology Wedge M-7: Assumption on biofuel synthesis

Energy share of fuel salaries in Austria	2010	2015	2020	2020
biodiesel and vegetable oil	7.04%	8.00%	10.00%	12.00%
bioethanol	3.62%	6.50%	7.00%	13.00%

Source: Molitor et al. (2009).

Implementation of EnergyTransition methodology for Technology Wedge M-7

In the project EnergyTransition all technology wedges are documented in a common framework as presented in Part B, chapter 3 and explained for mobility in the introduction (chapter 4.1) to ensure their comparability.

For Technology Wedge M-7 transport mileage in vehicle kilometres is defined as the mobility energy service (S) for road freight and road passenger transport. The energy service measured in vehicle-km is equal to the reference value in absolute terms. It increases according to the general assumptions (see chapter 4.2.1) relative to 2008 by 18%.

The useful energy intensity u is decreasing by 2% relative to 2008. The efficiency gains assumed in each storyline are expressed as usual in final energy intensity f. The overall change of final energy F is -1% relative to 2008. This effect incorporates solely the effects according to the general assumptions for freight transport and passenger transport named in section 4.2.1. The technology wedge in this storyline does not cause any changes in the energy parameters. The figures for changes relative to 2008 in service and energy indicators are shown in Table 4.55.

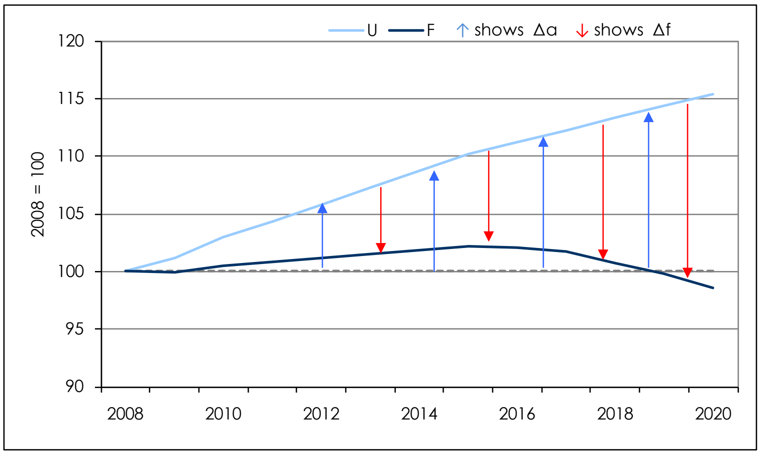
Table 4.55: Technology Wedge M-7: Summary of energy service and energy indicators

Increase of biofuels additions	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	18	118
Energy Intensities			
Useful Energy Intensity (u)	100	-2	98
Final Energy Intensity (f)	100	-15	85
Final Energy (F)	100	-1	99

Source: Own calculations.

According to the EnergyTransition methodology changes in useful energy intensity and energy services are given in Δa and changes in final energy intensity are given in Δf. In the storyline for Technology Wedge M-7 the changes of S, u and f relative to 2008 are summed up in Figure 4.20. It illustrates changes in final energy demand over time compared to 2008. Δa is positive, because S and u are increasing over time compared to the base year 2008. Δf expresses the change in final energy demand (F) due to a change in final energy intensity f. These two effects combined lead to a reduction of F by 1% compared to 2008. The changes in Δa are indicated by the light blue arrows; changes in Δf by red arrows (see Figure 4.20).

Figure 4.20: Technology Wedge M-7: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

The change of shares of energy sources between 2008 and 2020 is given in Table 4.56.

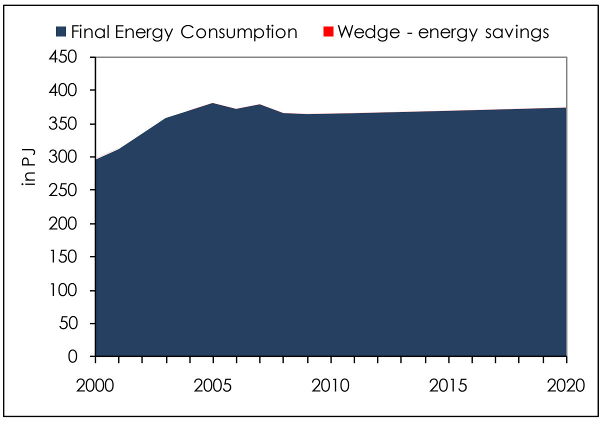
Table 4.56: Technology Wedge M-7: Effects on fuel mix

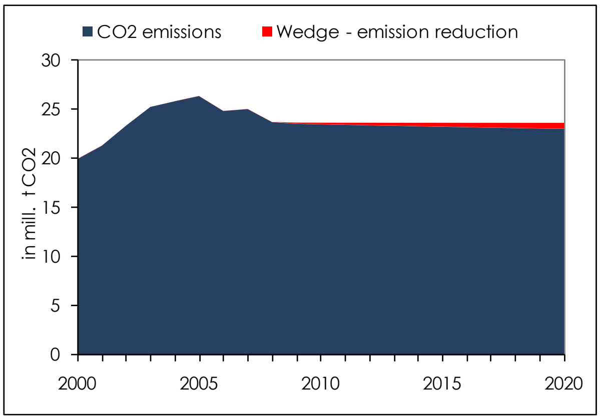
Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-3.4	86.1
Gas	2.8	0.4	3.3
Renewables	4.5	3.1	7.6
Electricity	3.2	-0.1	3.1
Total	100.0	0.0	100.0

Source: Statistics Austria (2009a), own calculations.

Final energy is not changing in this storyline as there is no change in energy service relative to the reference case which means that the energy needed to drive one kilometre is still the same only the share of biofuel additions has changed. Yet, the CO_2 emissions are reduced by 2.6% by 2020 relative to the reference value. This amounts to 600 kt fewer emissions relative to the reference scenario value for 2020 (see Table 4.57 and Figure 4.21).

Figure 4.21: Technology Wedge M-7: Effects on energy demand (left) and CO_2 emissions (right)





Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.57: Technology Wedge M-7: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	322.61	-8.06	-2.4	23.13	22.35	-0.60	-2.6
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	28.40	8.06	39.6	0.00	0.00	0.00	0.0
Electricity	11.56	11.60	0.00	0.0	0.00	0.00	0.00	0.0
Total	366.54	374.81	0.00	0.0	23.70	23.02	-0.60	-2.60

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

In Austria there are nine biodiesel production facilities with a production capacity of 365,000 t/year. The newly built bioethanol plant in Pischelsdorf has a capacity of 190,000 t/year. The demand for biofuels within this storyline due to the increase of biofuel addition is about 500,000 t in 2020. As the Austrian infrastructure can meet the additional needs of biofuels no additional investment costs are assumed.

However, there are higher production costs for biofuels relative to conventional fuels. In Steininger et al. (2007) the increase of production costs are estimated at 0.38-0.47 €/l higher than conventional diesel. In this storyline we calculate with additional production costs of 0.42 €/l. Due to indirect subsidy of about 0.5 €/l (considering the lower energy content of biofuel) from the public sector consumers face about the same price for biofuel and conventional fuel. The increase of production costs is given in Table 4.58.

Table 4.58: Technology Wedge M-7: Development of investment costs and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	0	0	0	0	0	0	0	0	0	0	0	0
Additional Costs	0	0	0	0	0	0	0	0	0	0	0	0
Operating costs	0	13	18	23	28	34	58	69	80	90	100	95
Additional Costs	0	13	18	23	28	34	58	69	80	90	100	95

Source: Steininger et al. (2007); own calculations.

About 50% of the price for biofuels account for agricultural production, oil extraction or conversion to ester. The rest is the refining and synthesis of biofuels. The agricultural production capacity for biofuels in Austria is estimated at 150,000 t for 2010 (Tribl, 2005) including the current acreage and the area of unused acreage. For meeting the increase in the storyline of up to about 500,000 t in 2020 there is a need for import of 30% in the future. Additionally it has to be considered that due to the subsidies for biofuel (roughly 0.5 €/l) expenditure reduction in other sections of the public budget have to be achieved, which lead to a reduction in public consumption.

Table 4.59: Technology Wedge M-7: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Products of agriculture, hunting and related services	25	25
Food products and beverages	25	25
Coke, refined petroleum products and nuclear fuels	50	50
Total	100	100

Source: Own calculations.

4.2.9 Technology Wedge M-8: Relocation of fuel consumption

The storyline for this technology wedge covers a relocation of fuel consumption by alignment of the Austrian fuel prices with the prices of the neighbouring countries. The characteristics of the technology wedge are summarised in Table 4.60.

Table 4.60: Summary Table for Technology Wedge M-8

Relocation of fuel consumption	
Energy service	Constant relative to reference
Technology/behavioural change	Export of fuel in vehicle fuel tanks is removed
Required capacity increase*	None
Diffusion path	Linear
Total investment	None
Operating costs	None
Emission reduction by wedge*	3.97 million t CO_2 in 2020

* Compared to reference scenario.

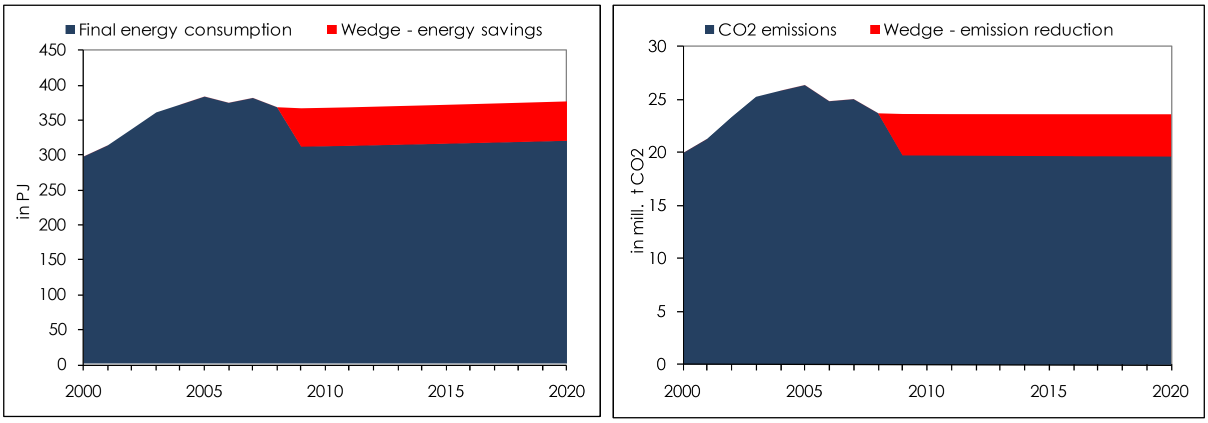
According to the UNFCCC accounting principles transport emissions are calculated based on total fuel sales in Austria. However, not all fuels sold in Austria are used within Austrian borders, but may be used in driving abroad (and thus GHGs are emitted abroad, 'export of fuel in vehicle fuel tanks'). This is mainly due to the price differential of fuel between Austria and the neighbouring countries. For the first five months of 2010 the average fuel price for diesel (including all taxes) in Austria was about 10 €cent lower than in Germany and even 12 €cent lower than in Italy. In Slovenia and Slovakia the price differential was one and 2 €cents, respectively in the first half of 2010. For gasoline the price was higher in Germany by 20 €cent in the first half of 2010 and in Italy by 18 €cent. Increasing the tax rate on fuel would decrease fuel consumption in Austria by foreign car drivers. On a global scale this would not reduce emissions when we assume that the increase of about 5 to 10 €cent per litre (as scheduled by the Austrian ministry of environment) does not induce changes in mobility behaviour. But it would lead to substantial decreases of Austrian CO_2 emissions and would help Austria to reach the emission targets. The Austrian Environmental Agency (UBA) estimates that 24.7% of the GHG emissions of 2008 are due to export of fuel in vehicle fuel tanks (Anderl et al., 2010). Currently export of fuel in vehicle fuel tanks is estimated within the range 15-30% of GHG emissions. For calculating the reduction potential of Technology Wedge M-8 we start with the tentative appraisal that 15% of the energy consumption in the road passenger and freight transport can be reduced by the relocation of fuel consumption.

Technology wedges M-1 to M-7 are explained within the Energy Transition methodology. For calculating the energy and emission changes in these technology wedges we use the bottom-up approach, starting with the transport performance in passenger and freight transport that is actually realised within Austrian borders. As total fuel consumption is given by total fuel sales in Austria export of fuel in vehicle fuel tanks cannot be explained within the bottom-up framework.

However we show the energy and emission reductions due to Technology Wedge M-8 relative to the reference scenario.

In Technology Wedge M-8 we consider a reduction of energy consumption for road transport by 15% relative to the EnergyTransition reference scenario. This leads to a reduction of energy consumption of the complete transport sector of 14.4% in 2020 relative to the reference value. Emissions decrease by 3.97 million tons in 2020 in energy source oil (see Table 4.61 and Figure 4.22).

Figure 4.22: Technology Wedge M-8: Effects on energy demand (left) and CO_2 emissions (right)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 4.61: Technology Wedge M-8: Effects on final energy consumption and related CO_2 emissions

Energy source	Final energy consumption				CO_2 emissions			
	2008	2020			2008	2020		
			Difference to Reference				Difference to Reference	
	in PJ	in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	0.01	0.00	0.00	0.0	0.00	0.00	0.00	0.0
Oil	328.11	274.45	-53.66	-16.4	23.13	18.98	-3.97	-17.3
Gas	10.41	12.20	0.00	0.0	0.57	0.67	0.00	0.0
Renewables	16.45	20.34	0.00	0.0	0.00	0.00	0.00	0.0
Electricity	11.56	11.60	0.00	0.0	0.00	0.00	0.00	0.0
Total	366.54	318.59	-53.66	-14.4	23.70	19.65	-3.97	-16.8

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

There are no explicit costs occurring in Technology Wedge M-8 because the emission reduction can be gained by simply changing still existing legal regulations. Depending on how this relocation of fuel consumption is initiated, there might easily be a (net) impact on government revenues, however.

4.2.10 Combination of Technology Wedges

The emission reduction potentials of each technology wedge cannot be aggregated easily because of overlapping effects. Transport performance once reduced by better spatial planning for instance cannot be substituted by alternative propulsion technologies anymore. Thus, the effect of each technology wedge itself, when used in combination, is less intense than when considered individually. In order to calculate the total emission reduction potential of the transport sector the potential of each technology wedge is determined step by step in a logical order. First, we determine the reduction potential of an efficient transport saving land use (M-1). The change in transport performance and modal split is used as the basis for the calculations of the next technology wedge, the improvement and enhancement of public transport (M-2). Next, we calculate the effects of non-motorised transport using the change in mileage from the previous technology wedge as new input data (M-3). The remaining transport performance in motorised transport is used to determine the effects of a shift from conventional vehicles to alternative propulsion technologies (M-4). Besides passenger transport we calculated the effects of an improved freight transport considering a shift from road transport to rail and efficiency measures (M-5). Next, we determine the reduction potential of an increase in efficiency of conventional vehicles by lightweight construction (M-6). Finally, for the remaining fuel quantity required in passenger and freight transport the share of biofuels is increased (M-7). The amount of reduced final energy demand and CO_2 emissions by relocating fuel consumption abroad, which is determined independently from the other technology wedges, is added (M-8). As a result total final energy demand can be reduced by 83.59 PJ in 2020 compared to the reference scenario and accordingly CO_2 emissions can be decreased by 6.56 million t (see Table 4.62 and Table 4.63).

Table 4.62: Final energy demand in the transport sector in 2020

Technology Wedge		Final energy consumption 2020 Difference to Reference in PJ					
		Oil	Coal	Gas	Renewables	Electricity	Total
M-1	Efficient transport saving land use	-5.37	0.00	0.00	-0.27	0.03	-5.61
M-2	Public transport	-4.66	0.00	0.00	-0.22	0.49	-4.40
M-3	Non-motorised transport	-4.67	0.00	0.00	-0.23	0.00	-4.90
M-4	Alternative propulsion technologies	-2.08	0.00	0.00	-0.14	0.33	-1.88
M-5	Freight transport	-5.44	0.00	0.00	-0.33	1.35	-4.42
M-6	Efficiency increase of conventional vehicles by mass reduction	-5.86	0.00	0.00	-0.29	0.00	-6.15
M-7	Alternative fuels	-6.88	0.00	0.00	6.88	0.00	0.00
M-8	Relocation of fuel consumption	-53.40	0.00	0.00	-2.82	0.00	-56.22
	Total	-88.37	0.00	0.00	2.58	2.20	-83.59

Source: Statistics Austria (2009a, b); own calculations.

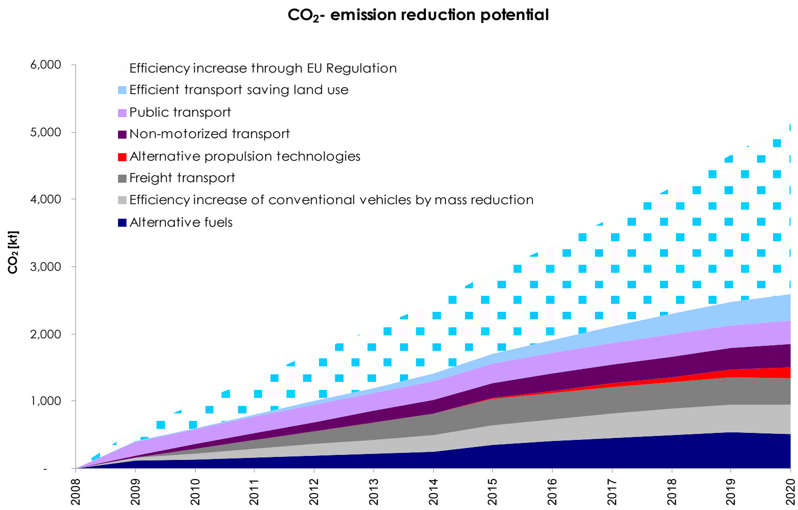
Table 4.63 shows the CO_2 emission reduction potentials for Wedges M-1 to M-8 in three ways. First, in a combined way; second contrasted with the reduction potential when wedges are not combined and third, when wedges are not combined when efficiency gains as considered in the general assumptions of the reference case are not included i.e. the reduction potential when the EU regulation (EC) No 443/2009 on emission standards for new passenger cars would not have been implemented in Austria. This is to give an indication of the emission reduction potential for each wedge when none of the others (or the efficiency increase of the EU regulation) are implemented. Finally, the effect of the efficiency gains from EU regulation (as is assumed in the general assumptions, and thus presupposed for all wedges) is displayed in Figure 4.23.

Table 4.63: CO_2 emissions in the transport sector in 2020 (wedges combined and separately)

Technology Wedge		CO_2 emissions 2020 Difference to Reference in mt		
		Combined technology wedges	Individual technology wedges	Individual technology wedges - no efficiency increase
M-1	Efficient transport saving land use	-0.40	-0.40	-0.50
M-2	Public transport	-0.35	-0.46	-0.59
M-3	Non-motorised transport	-0.35	-0.42	-0.52
M-4	Alternative propulsion technologies	-0.15	-0.15	-0.17
M-5	Freight transport	-0.40	-0.40	-0.40
M-6	Efficiency increase of conventional vehicles by mass reduction	-0.44	-0.50	-0.63
M-7	Alternative fuels	-0.51	-0.60	-0.70
M-8	Relocation of fuel consumption	-3.97	-3.97	-3.97
	Total	-6.56		

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Figure 4.23: CO_2 emission reduction potential for wedges combined (2008 -2020)



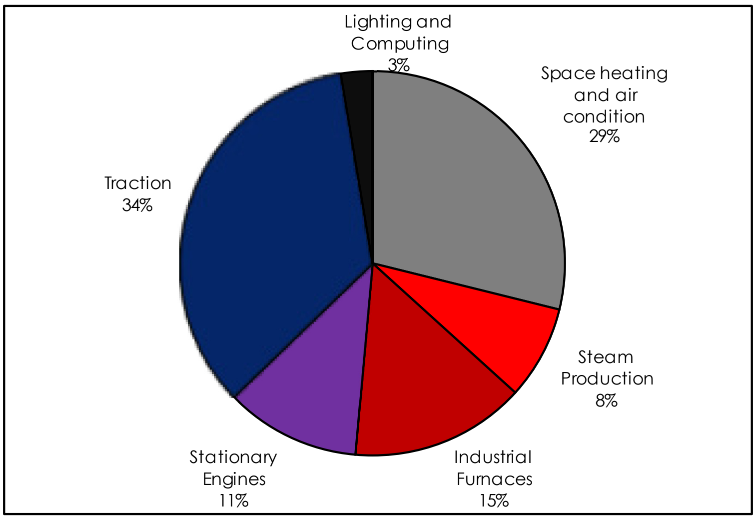
Source: Own illustration.

5 Technology wedges for buildings

5.1 Introduction

The building sector plays a central role in achieving the objectives of the Austrian climate and energy policy. Its share in final energy consumption is almost 30% and therefore measures leading to a reduction of energy demand have a very high relevance. Figure 5.1 visualises the significance of the building sector (space heating and cooling) in total energy demand: 29% (= 314 PJ) of final energy consumption (1,088.5 PJ in 2008 according to useful energy analysis 2008) are used for space heating.

Figure 5.1: Total final energy consumption in 2008 (overall 1,088.5 PJ)



Source: Statistics Austria (2009b).

The main energy services associated with the structure and quality of buildings are:

- heating and cooling,
- hot water supply,
- ventilation,
- and lighting.

Other services are related to cooking, washing, and other energy consuming services like use of consumer electronics, communication and ICT, and use of other appliances (multimedia, Hi-Fi, etc.).

Heating of buildings is characterised by the specific heating demand (in kWh/m² per year) related to the building area, cooling of buildings respectively by the cooling demand. The main energy sources for heating of buildings are fossil fuels and renewable energy sources like biomass. At present fossil fuels (gas, oil, to a small extent coal/coke) are the predominant energy sources, but renewable sources gain in importance, e.g. biomass of all forms (logwood, pellets, wood chips, waste heat, etc.) as well as solar heating (though mainly used for hot water preparation) or district heating systems running on renewables or waste heat. Electrical heating, which played a role in the past, is increasingly substituted. Heat is supplied in heating systems of high temperature and low temperature, in central and decentralised systems as well as through cogeneration systems.

Hot water is produced mainly by boilers, electric heaters or by district heating on the basis of fossil fuels or renewable sources. Increasingly solar heating and heat pumps are being used. The share of solar heat in Austria in the household sector is currently about 1% (ca. 2.2 PJ), ca. 3.6 million m² of collectors were installed in 2007/2008[16]. Solar collectors are usually installed on the roofs or integrated in façades of buildings. The share of heat pumps for heating and hot water generation is similar to solar energy use and reaches currently about 1% (ca. 2.9 PJ).

Large buildings especially in the service sector (office buildings, hotels, etc.) or production halls need an in-house ventilation system. Depending on the type of system and the usage factor, ventilation is a significant consumer of energy. Controlled space ventilation installed in passive houses in combination with heat recuperation becomes increasingly important together with the thermal improvement of the building stock.

Energy demand for cooking is generally met electrically and by gas.

The energy used for lighting, communication and consumer electronics is part of electricity demand. This category is characterised by a significant increase in endowment and use of appliances (LCD and plasma TVs, HiFi, DVD, video, computers, play stations and gaming and other equipment) and thus growing energy demand.

Generally, all groups of services are strongly influenced by individual user behaviour and thus show a vast spread of specific energy consumption with resulting potentials for energy savings.

The structure of the existing building stock in Austria can be summarised as follows:

- Residential buildings
    - with one or two dwellings (single/double family house: S/DFH)
    - multiple-storey residential buildings (multi-family house: MFH)
- Non-Residential buildings, as
    - offices (private and public office buildings)
    - hotels and restaurants
    - whole and retail sale (incl. warehouses)
    - culture, education (e.g. schools, kindergartens), social & health (e.g. hospitals, retirement homes) buildings.

[16] See BMLFUW (2008).

Table 5.1 presents the existing data on the building stock. While in the sector of residential buildings data about quantity and useful surface area exist, in the sector of non-residential buildings surface data are not available. The right column indicates the useful surface area. Average surface areas of service buildings had to be estimated based on typical building sizes.

Table 5.1: Building stock in 2008

Structure of the building stock	Number	Share in %	Considered surface in 1.000 m²
Building stock	2,046,712	100	
Residential buildings	1,764,455	86	292,384
S/DFH	1,557,420	76	176,050
MFH	207,035	10	116,334
Non-residential buildings	282,257	14	197,598
Hotel	35,837	2	48,667
Office	32,235	2	90,950
Whole/retail sale	33,065	2	42,323
Culture/education/health	15,393	1	15,658

Source: Building and Dwelling Census 2001, Statistics Austria, BIG (2008), BMWA (2008), WKO statistics (2008), ecofacility (2008); own calculations.

Due to the high relevance of buildings for final energy consumption (see also Figure 5.2) improvement in energy efficiency and a significant reduction of energy demand in existing and new buildings are of high priority.

Considerable improvements have taken place in the sector of new buildings in the recent past. Low energy and passive house standards have become state-of-the-art as a result of continuous improvements in the building legislation (enforcement of stricter building codes, as a main incentive for all buildings receiving public funding).

However, the existing building stock still provides a high potential for energy efficiency measures through substantial thermal refurbishment of one and two family houses and (public and private) service buildings. The share of single and double family houses (S/DFH) is about 76% of the building stock (see Table 5.1). The highest potential for energy savings could be realised in buildings constructed in the post-war era (between 1945 and 1980). Savings up to 85% of the current heating demand are possible if residential buildings (single/double family houses) are refurbished according to Low Energy Standard (LES), which is equivalent to a specific energy demand of 50 kilowatt-hours per square meter and year (kWh/m².a). Typical measures to achieve this level are related to the building envelope (replacement of windows, insulation of façades including base, roof/ceiling insulation, insulation of basement ceiling). The energy savings of multiple-storey residential buildings (multi-family houses) are lower but still amount up to 70%.

In order to realise the potential energy savings in the whole building sector and therefore significant CO_2 reductions, the renovation rate – at present between ca. 1% (family houses) and 2% (public service buildings) annually has to be raised significantly within the next 10 years (our assumption: up to ca. 5% per year of the existing building stock, i.e. surface area in the specific year that has not been refurbished so far).

The improvement of the thermal quality of buildings should at the same time also comprise measures to improve the efficiency of existing heating systems and switch to low temperature systems based on renewables (e.g. solar heating, heat pumps or wood-based systems).

Based on the historical development a reference scenario of energy use in buildings (until 2020) has been established. Building on these reference values, different options (storylines) have been developed that provide options to significantly increase energy efficiency in the building sector until 2020. The further development until 2050 is qualitatively indicated by trend scenarios.

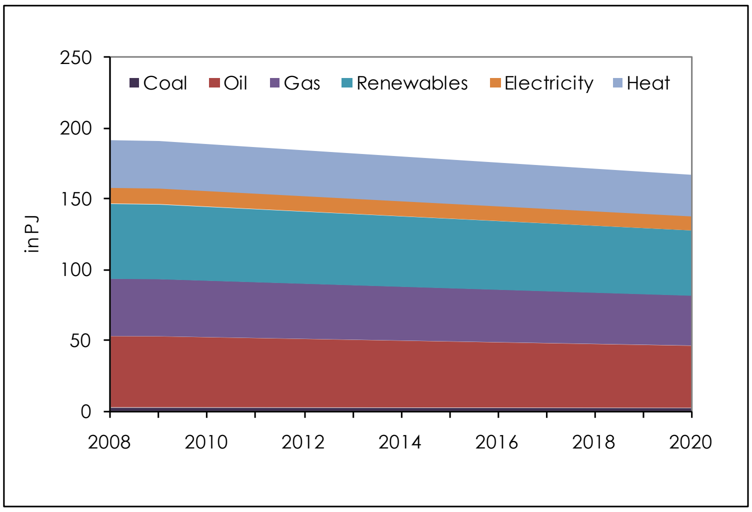
5.2 Reference scenarios for the building sector

5.2.1 Reference scenario: building refurbishment

Figure 5.2 shows the development of final energy consumption for space heating and a reference scenario for energy use by energy sources up to 2020. According to the reference scenario, total heating demand of the building stock (residential and service) will decrease from about 192 PJ in 2008 to about 167 PJ in 2020 (-13%). Underlying assumption is a more or less stable refurbishment rate of 1-1.2% of the un-refurbished housing stock and a demolition rate of 0.4% of existing residential buildings p.a. (see ÖRÖK, Statistics Austria, 2005). A lower value of the demolition rate was assumed for non-residential buildings (from about 0.05% to 0.1%).

Generally, the refurbishment rate is being calculated as the amount of useful surface area (in %) being retrofitted in a specific year related to total surface area of the building stock of 1945-1980 (only diminished by the demolition rate) that remains to be refurbished in the respective year. Therefore, assuming a stable refurbishment rate of e.g. 1% p.a. in a reference scenario, the total area to be refurbished will diminish in absolute terms between 2008 and 2020 (because from year to year there is less area still to be retrofitted).

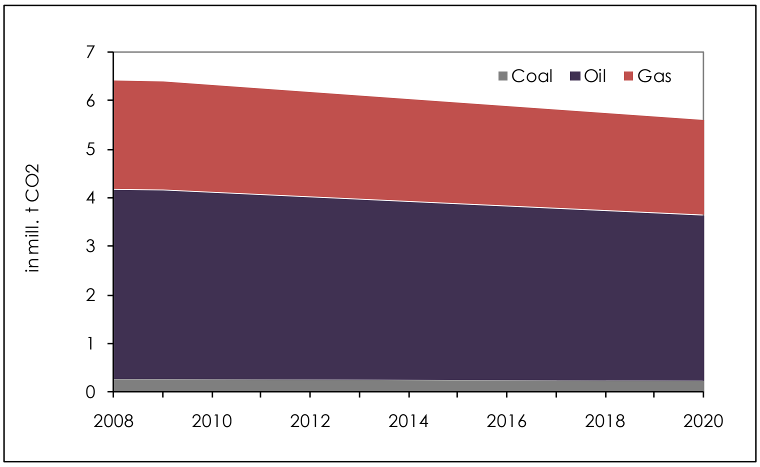
Figure 5.2: Final energy demand for space heating – reference scenario building refurbishment



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

The corresponding trend of the CO_2 emissions in the reference scenario, related to residential and service buildings, is given in Figure 5.3. Emissions from electricity and heat generation are not included in the building sector, as they are attributed to the energy sector and therefore considered in Part B, chapter 7. Total CO_2 emissions corresponding to space heating decrease from approx. 6.4 million t to about 5.6 million t per year in the reference scenario for building refurbishment.

Figure 5.3: CO_2 emissions in the reference scenario building refurbishment



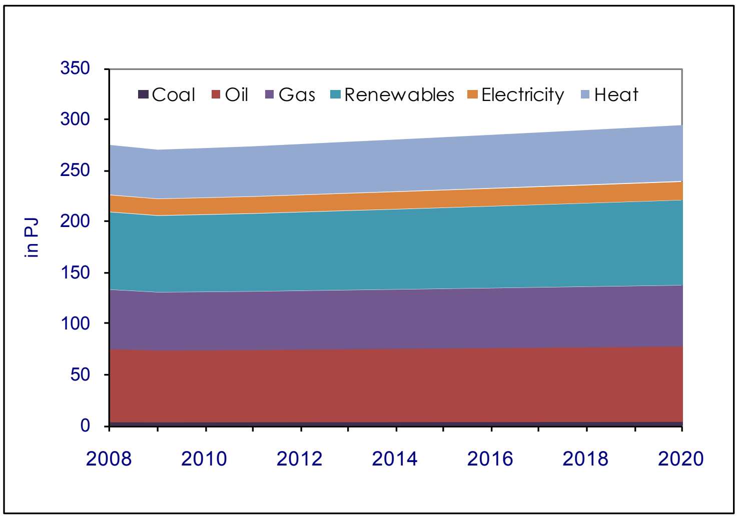
Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

5.2.2 Reference scenario: new buildings

Based on the demonstrated development of energy consumption of space heating in residential and service buildings according to the useful energy demand in the

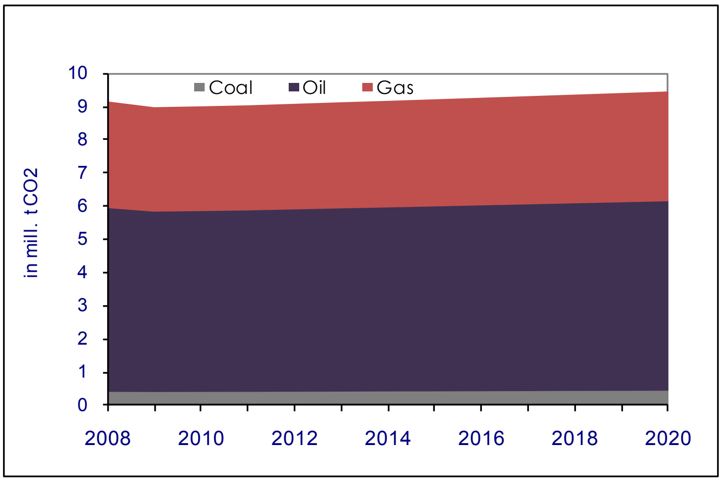
EnergyTransition reference scenario (increase from 274 PJ in 2008 to about 294 PJ in 2020) and based on the existing building stock, a construction rate of new buildings of 1% (2008) to 1.2% (2020) p.a. is assumed. Stable shares of the different energy sources used between 2008 and 2020 in the new building sector (28% heat from renewables, 26% from oil, 21% from natural gas, 18% district heating, 6% electricity and 1% from coal) as well as only minor improvements of specific energy demand (from ca. 70 to ca. 60 kWh/m².a for the whole new building stock) by 2020 are assumed in this reference scenario. Figure 5.4 and Figure 5.5 demonstrate the development of final energy demand and of CO_2 emissions (9.2 to 9.5 million t) of the building sector between 2008 and 2020 in the reference scenario. Based on these assumptions a technology wedge for new buildings is defined, see chapter 5.3.2.

Figure 5.4: Final energy demand for space heating – reference scenario new buildings



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Figure 5.5: CO_2 emissions in the reference scenario new buildings



Source: Statistics Austria (2009b); own calculations.

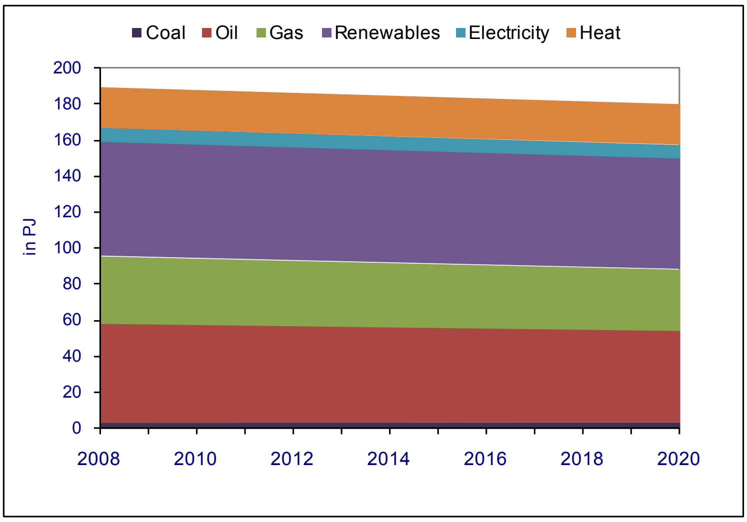
5.2.3 *Reference scenario: heating systems*

Heating systems in buildings bear an additional potential for improvements in energy efficiency. Especially the great number of individual heating systems installed in residential buildings is considered to be partly obsolete, due to mainly old and inefficient boilers (those aged 25 years and more), improper controls and/or piping systems. Therefore it is obvious to assess the energy saving potential for improved heating systems that in the long term will also consider a higher penetration of renewable energy sources (biomass, heat pumps, district heating from renewables – integration of solar systems and increasing their penetration for producing heat and hot water are considered separately, see next section).

In the reference scenario for heating systems it is assumed that the energy intensity attributed to the overall effectiveness of heating systems (not considering the thermal quality of the building itself) is about 5% lower in old, inefficient systems, compared to new, efficient ones. The replacement rate of heating systems is considered to be around 2% p.a. (assumption: replacement of heating systems every 25 years or half the period of a regular thermal building refurbishment that is ca. 50 years). In addition, the distribution of energy sources will be changing slightly in favour of renewable energy sources, on the basis of the assumptions made in the reference scenario.

Figure 5.6 and Figure 5.7 show the development of final energy demand and the corresponding CO_2 emissions of space heating in the reference scenario. In this case, only the heat demand of the residential sector is considered for a technology wedge on improved heating systems (due to a lack of proper information on heating systems in use in non-residential buildings). While estimated energy demand in this sector is ca. 189 PJ in 2008 and will increase to ca. 198 PJ in 2020, Figure 5.6 visualises the effects of a yearly assumed efficiency improvement of about 5% and a demolition rate of about 2% (in line with the overall demolition rate of buildings up to 2020) between 2008 and 2020 (from 189 PJ to 180 PJ) caused by improved technologies of the new heating systems.

Figure 5.6: Final energy demand for space heating– reference scenario heating systems (residential buildings)

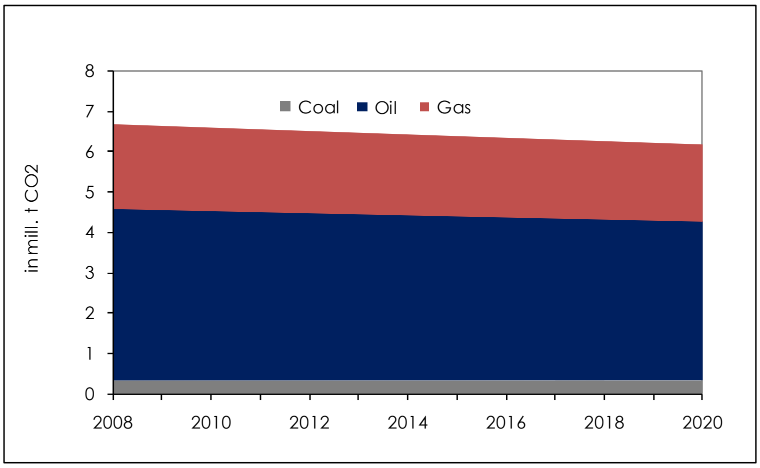


Source: Statistics Austria (2009b); UNFCCC (2010); own calculations.

As Figure 5.6 shows, the energy mix will change only marginally between 2008 and 2020 in the reference scenario. The fossil fuels oil (29%) and gas (20%) remain the dominant energy sources, their share decreases by about 1% until 2020, the share of coal remains at 2%. The renewable energy sources (33%) increase slightly by about 1% until 2020. The share of electricity (4%) and the share of district heating (12%) are remaining almost constant.

According to the trend and including the improved efficiency (see above) the CO_2 emissions of residential space heating decrease from 6.67 million t in 2008 to 6.17 million t CO_2 in 2020 (see Figure 5.7) Again, emissions of electricity and heat are not included in the building sector, as they are part of the energy sector and therefore considered in Part B, chapter 7.

Figure 5.7: CO_2 emissions in the reference scenario heating systems



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

5.2.4 *Reference scenario: solar heating*

In the past, solar heating was mainly used for hot water generation in residential buildings, especially in single/double family houses, for swimming pool heating and to a minor degree to support space heating. While in the past unglazed plastic absorbers had a large share in the yearly installed collector area, currently their share is only small (about 3% in 2007). For hot water generation basically flat plate collectors are used, only to a minor degree tube collectors (about 1.2% in 2007, see BMLFUW (2008)). Beside single/double family houses, also multi-family houses and increasingly public service buildings, like schools, communal buildings as well as private service buildings, especially hotels, are using solar hot water generation. Additional to hot water generation the use for space heating as well as combined plants (coverage 10 – 20%) become more important. Combined plants generate both heat and hot water[17]. The installed collector area of flat plate and tube collectors was 3 million m² (2.1 GW_{th}) in 2007/2008 with a coverage of the total low temperature demand of about 1% (see BMLFUW, 2008).

Figure 5.8 shows the development of final energy demand for space heating and hot water and the trend for the energy sources used up to 2020 in the EnergyTransition reference scenario. Due to the dynamics in this market segment and large potentials for technology advancements (see BMVIT, 2010a), e.g. flat plate collector technology based on novel materials, collector production methods, high quality vacuum tube collectors, stratified hot water storage, electronic controllers, system technology (like solar combi-systems with a burner directly integrated into the storage), large-scale solar thermal systems combined with seasonal heat stores, advanced applications (cooling and combi-systems, solar heating is being considered a specific technology wedge that could contribute considerably to energy and CO_2 savings in the building sector. For the definition of a technology wedge scenario the residential and the service sectors[18]) are considered. The estimated energy demand will decrease from ca. 269 PJ in 2008 to ca. 232 PJ in 2020 (14%).

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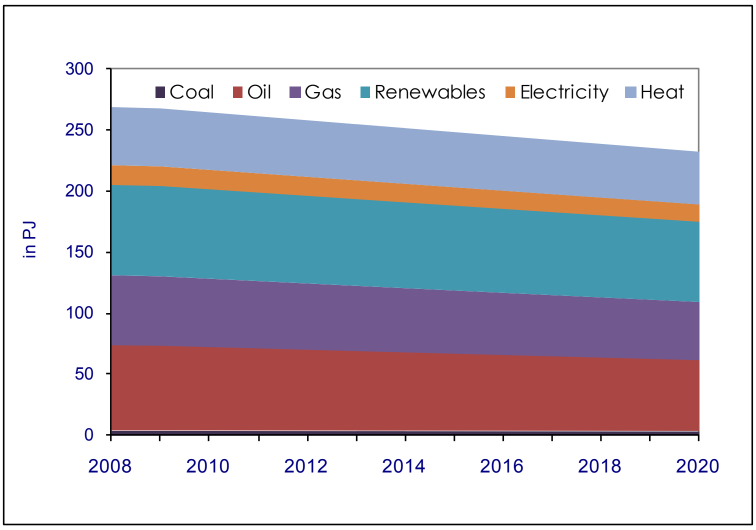
[17] While solar hot water generation depends on the number of persons per household (on average 2 m² collector area and 100 m³ hot water tank are calculated per person) the collector area and storage tank capacity for space heating conforms to the favored coverage and available area on the roof. An average size of combined solar plants is e.g. 20 m² collector area and 1 m³ storage.

[18] The Useful Energy Analyses (Statistics Austria, 2009b) differentiates hot water preparation as follows: In the household sector hot water is not integrated in the category space heating and cooling, but included in the category industrial furnaces besides cooking. In the service sector hot water generation is included in the category space heating and cooling.

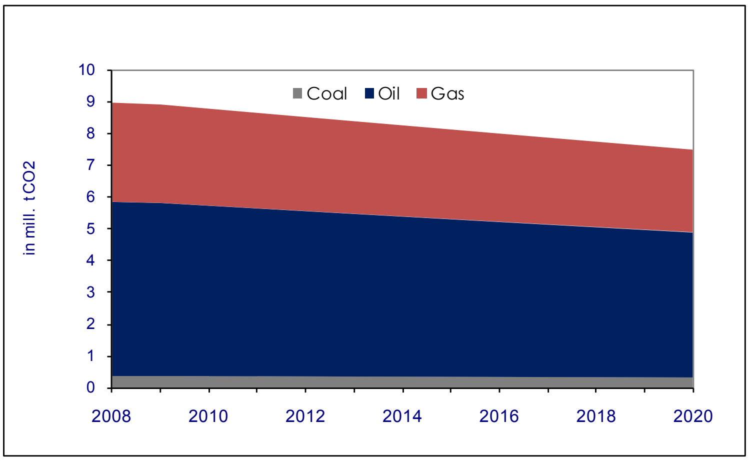
Figure 5.8: Final energy demand for space heating and hot water (residential buildings and other services) – reference scenario solar heating



Source: Statistics Austria (2009b); UNFCCC (2010); own calculations.

The corresponding reference path for CO_2 emissions from space heating and hot water generation of residential and service buildings is given in Figure 5.9. CO_2-emissions decrease from 9.0 million t in 2008 to 7.5 million t CO_2 in 2020 (-17%). Emissions from electricity and heat are once more not included in the building sector, and will be addressed in Part B, chapter 7 on the supply of electricity and heat.

Figure 5.9: CO_2 emissions in the reference scenario space heating and hot water (residential buildings and other services)



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

5.2.5 Reference scenario: electricity production through photovoltaics

Although the reference scenario as well as the technology wedge considered here refer to photovoltaics a short overview of other technologies that help achieve the status of a zero-energy building is given here.

Zero-energy buildings – buildings that produce as much energy as they consume – represent the cutting edge of highly efficient designed buildings. These buildings, which require state-of-the-art energy-efficient construction to reduce the heat demand to an absolute minimum will additionally produce electricity for own purposes – from a variety of renewable energy sources used, such as wood biomass or bio-wastes. Micro-generation can in the future become a very efficient and thus important way of producing energy needed in buildings.

Such micro-generation technologies can for instance be:

- Micro-CHP (combined heat and power) systems producing heat and simultaneously electricity for own purposes from nearly all energy sources (natural gas as well as renewables such as biomass or bio-wastes) [19]
- Micro wind power stations: small wind turbines (typical capacity up to 15 kW_p) located on (façade, roof integrated) or near the building
- Micro hydro systems: produce power from flowing water at typically low differences of elevation and/or low water flow
- Photovoltaics: solar energy in general is providing an insatiable potential for production of thermal and electrical energy. As PV is the most advanced technology of the ones listed here it will be taken as one example for decentralised electricity production or for achieving the concept of "zero-energy buildings" or "plus-energy houses" (those that produce more energy from renewable sources than they import from external sources), see also chapter 10.2.

The main advantage of all these technologies is the principle of supporting decentralised energy production, which in the past was mainly focused on satisfying the huge heat demand in buildings, but in the future will be primarily used to cover also the own electricity demand. The concept of "smart grids" is still in its infancy, but in the future "intelligent" electricity networks will integrate the behaviour and actions of all agents connected to it – energy generators, consumers and those that do both – in order to efficiently deliver sustainable electricity supplies. Distributed generators of electricity will therefore become important players in the energy system.

The reference scenario described here is referring to the share of PV in total electricity supply that is currently produced mainly in public plants (in Austria large hydro power, thermal power and renewables). Electricity from renewables, especially photovoltaics in buildings, has the potential to replace some of the capacities of large power plants through decentralised

[19] Bundesverband Kraft-Wärme-Kopplung eV (2006), Mikro-KWK-Anlagen and Haferl, A. (2010).

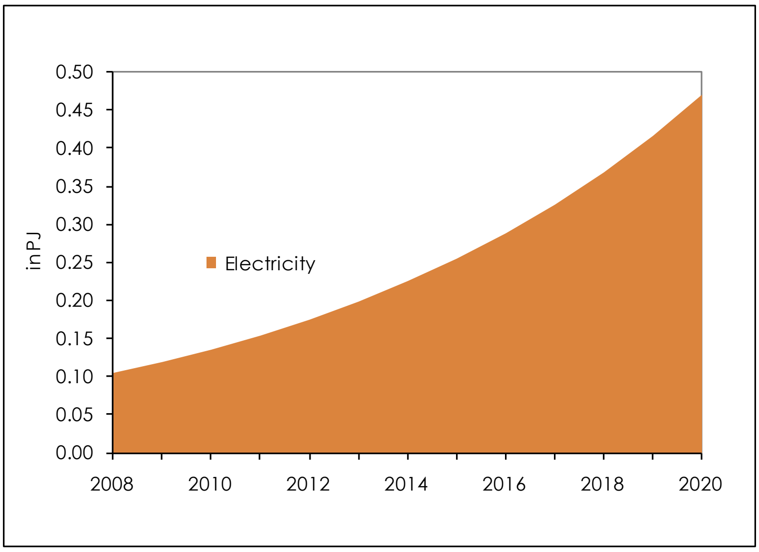
production units. Electricity generation and relevant substitution of energy sources is addressed in Part B, chapter 7.

Electricity demand of the sectors considered for the use of photovoltaics (household and service sector) increases from 101 PJ (in 2008) to about 114 PJ (+13%) in 2020. The supply of solar electricity in the reference scenario increases very moderately from 32 MW_p in 2008 to 130 MW_p in 2020, corresponding to an energy production from 0.105 PJ in 2008 to about 0.47 PJ in 2020 (or about 0.4% of total electricity demand).

The main assumptions for the development of the PV market are:

- annual increase of installed capacity on average 12%,
- 1% p.a. improvement of the system efficiency of PV plants until 2020 (increase by 10% to about 22% on average)[20].

Figure 5.10: Final energy demand photovoltaics – reference scenario



Source: Statistics Austria (2009b); own calculations.

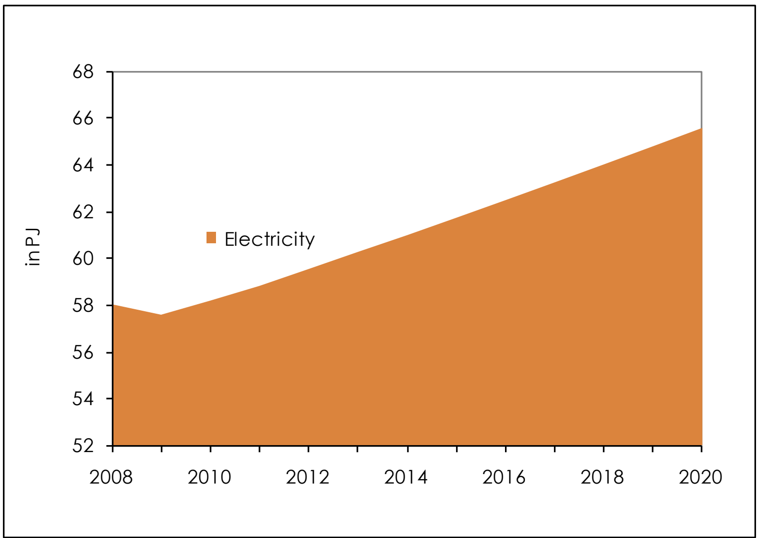
5.2.6 Reference scenario: energy optimised appliances

The increasing use of energy optimised appliances, lighting and equipment in the household sector is an important source for energy savings in addition to the already described potentials for technology wedges. While on the one hand the appliance stock per household is increasing and generates a rising electricity demand on the other hand a considerable part of the existing household appliances are often outdated and inefficient. Therefore a continuous replacement of old appliances through new super-energy efficient equipment

[20] International developments in PV R&D show that the demand for PV panels to produce 1 kW_p will decrease from currently 8-10 m² (system efficiency typically 12%-14%) to at least 3-5 m² by 2050. The total system efficiency will therefore go up to at least 30% (see BMVIT, 2007).

will be considered in Technology Wedge B-5. The development in the reference scenario extrapolates past trends in energy demand with only low efficiency improvements between 2008 and 2020. So the electricity demand of a four person household with an average of 4,076 kWh/a (2008) increases to 4,600 kWh/a by 2020 according to the Useful Energy Analysis (Statistics Austria, 2009b) and own calculations. Figure 5.11 illustrates the development of electricity demand in the household sector (increase from 58 PJ to 65.6 PJ – including space heating and cooling – at about 13%) between 2008 and 2020 in the reference scenario.

Figure 5.11: Final energy consumption of appliances – reference scenario



Source: Statistics Austria (2009b); own calculations.

5.3 Storylines for technology wedges in the building sector

In the following, a set of technology wedges is defined and described in order to achieve significant energy and emission reductions in the building sector.

The following five technology wedges are analysed:

- B-1 – Thermal refurbishment of existing buildings according to Low Energy Standard
  Renovation rate will be gradually increased from approx. 1% to 5% (until 2020).
- B-2 – Construction of new buildings according to Passive House Standard (PHS)
  New buildings will increasingly meet PHS with a significantly increased penetration rate until 2020.
- B-3a – Replacement of heating systems by more efficient systems based on renewables
- B-3b – Intensified use of solar heating for space heating and hot water preparation
- B-4 – Increased power production from photovoltaics in zero energy buildings
  Roofs of refurbished buildings and new buildings will be equipped with photovoltaic

panels to provide a significant amount of electricity needed in (near) zero energy buildings of the future.

- B-5 – Energy optimised appliances, lighting and equipment
  Continuous exchange of obsolete appliances through new super-energy efficient equipment.

The following useful surface areas are underlying the calculation of the technology wedges.

Table 5.2: Useful surface areas (2008)

Technology Wedge		Total useful surface areas (Basis 2008)	in 1,000 m²
B-1	Renovation	Residential buildings (1945-80), Non-residential buildings	253,534
B-2	New building	Residential buildings *) Non-residential buildings	518,227
B-3a	Replacement heating	Residential buildings (1900-90)	163,326
B-3b	Solar heating	Residential buildings (1900-90) Non-residential buildings	320,325

*) Based on the building stock (all construction periods). Non-residential buildings (considered are public buildings (administration, schools) and private service buildings (hotels, offices, retail) of all construction periods).
Source: Building and Dwelling Census 2001, Statistics Austria, BIG (2008), BMWA (2008), WKO statistics (2008), ecofacility (2008); own calculations.

5.3.1 Technology Wedge B-1: Thermal refurbishment of existing buildings – gradual increase of the renovation rate from 1% to 5% per year by 2020

The technology wedge covers the thermal refurbishment of existing buildings according to Low Energy Standard. The renovation rate of at present approximately 1% p.a. of residential buildings and of service buildings – between ca. 0.7% (private service buildings) and 2% (public service buildings) – will be gradually increased to about 5% per year by 2020 related to the residential building area of the period 1945-1980 and for non-residential buildings for all periods. It has to be noted though that the refurbishment rate in residential and non-residential buildings increases differently. While it is assumed that the renovation rate of the residential buildings (1945-80) will achieve 5% in 2019, for non-residential buildings the penetration rate differs, i.e. in public service buildings the higher renovation rate will be achieved faster (5% in 2019) than in private service buildings (5% in 2020).

The main assumptions and characteristics of the technology wedge are summarised in Table 5.3.

Table 5.3: Summary Table for Technology Wedge B-1

Thermal refurbishment of existing buildings according to Low Energy Standard	
Thermal refurbishment	Energy savings of S/DFH: up to 247 kWh/m², MFH: up to 104 kWh/m², non-residential service buildings: up to 94 kWh/m²
Energy service	253.5 million m² useful surface area (2008) of residential building 1945-1980 and non-residential buildings of all building periods, 105.8 million m² to be retrofitted up to 2020, shares of energy sources for heating remain constant up to 2020
Technology / Building code	Low energy standard (LES), i.e. max. 50 kWh/m².a
Required capacity increase	Increase of the renovation rate from 1% to 5% per year in 2020
Diffusion path	Linear
Total investment	6,034 million € in 2020, accumulated 55,682 million € by 2020 (additional costs of 4,826 million € in 2020, accumulated 38,985 million € by 2020)
Operating costs	302 million € in 2020 in refurbished buildings
Emission reduction by wedge*	1.2 million t CO_2 in 2020

* Compared to the reference scenario.

Technology Wedge B-1 covers building renovation, namely renovation of residential buildings, private service buildings and public service buildings.

Residential buildings of the post war period (1945 to 1980) are considered as the building stock with the highest saving potential, with the main target to increase the renovation rate of the S/DFH and MFH of this building period of at present 1% to 5% in 2019. The share of the post war buildings is about 40% of the total building stock. Furthermore, a demolition rate of residential buildings of 0.4% p.a. (see ÖRÖK, Statistics Austria, 2005) and a share of already refurbished buildings of about 14% (of the existing building stock constructed before 1980) are assumed. The energy service S is expressed as the useful surface area (in m²). Starting with a yearly renovation rate of about 1% of the useful surface area in the base year 2008, approximately 968,000 m² are retrofitted in the first year. In 2019, the renovation rate of 5% will be achieved and altogether ca. 42.7 million m² (44%) of the post war residential buildings will be retrofitted by 2020. The share of the retrofitted buildings in 2020 in all residential buildings amounts to 15%.

Furthermore, public service buildings of all construction periods up to 2009 are considered for retrofitting. The actual renovation rate in this area is estimated to be approx. 2% (assumptions from different sources using figures up to 4% cannot be substantiated[21]). Considered are official buildings of the Federal Government, the state governments and communities (mostly

[21] The renovation rate differs in the various building categories (see Table 1), from about 0.7% at private non residential buildings to about 2% up to 4% in public buildings (the last one is not substantiate) and 0.8% in family houses to 2.0% in communal residential buildings (see Statistics Austria, IBW-Institut für Immobilien, Bauen und Wohnen GmbH, BIG , 2008)

managed by the BIG – Bundesimmobiliengesellschaft), as well as schools and other public buildings, altogether approx. 20,820 buildings. As the data base for non-residential buildings is insufficient, assumptions had to be made regarding the number of buildings, building surface areas (based on inquiries) as well as average values of useful surface areas, specific energy demand, demolition rates etc. With an assumed yearly renovation rate of about 2% of the useful surface area, in the base year 2008 1.38 million m² are to be retrofitted. In 2020, altogether 31.6 million m² will be retrofitted in Technology Wedge B-1.

Besides the public service buildings also private non-residential buildings of all periods up to 2009 are considered for retrofitting, namely private office buildings, whole and retail sale buildings and hotels, altogether approx. 73,058 buildings. The assumed yearly renovation rate of about 0.7% of the building surface area is equivalent to about 615,000 m² (in the base year 2008). Until 2020 it is assumed that a renovation rate of 5% will be achieved and a total of 31.4 million m² will be retrofitted. Table 5.4 illustrates the annual renovation rate for all buildings considered.

Table 5.4 Renovation rate of refurbishing buildings

Refurbishing buildungs	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Refurbishing rate % p.a.	1.2%	1.4%	1.7%	2.1%	2.7%	3.0%	3.4%	3.8%	4.1%	4.4%	4.7%	5.0%	5.0%

Source: Statistics Austria (2007); own calculations.

Implementation of EnergyTransition methodology for Technology Wedge B-1

Considering the implementation of the refurbishment measures in all types of buildings as described, the effects of the Technology Wedge B-1 regarding energy savings and CO_2 emission reductions achieved in the building sector are estimated to amount to about 1.2 million t CO_2 in 2020. Table 5.5 summarises the changes in the energy indicators for Technology Wedge B-1.

Table 5.5: Technology Wedge B-1: Summary of energy indicators

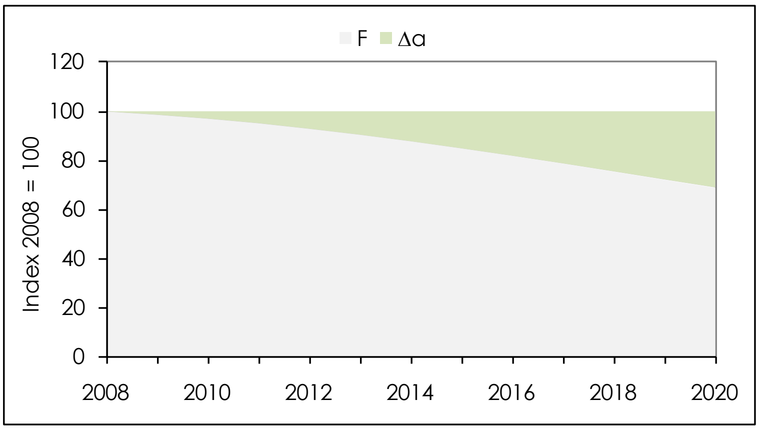
Space Heating - Households & Service	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Services			
Energy Service	100	-3	97
Energy intensities			
Useful Energy Intensity (u)	100	-29	71
Final Energy Intensity (f)	100	0	100
Final Energy F	100	0	69

Fuel Shift	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	1.5	0.0	1.5
Oil	26.1	0.0	26.1
Gas	21.3	0.0	21.3
Renewables	27.6	0.0	27.6
Electricity	6.0	0.0	6.0
Heat	17.6	0.0	17.6
TOTAL	100.0	0.0	100.0

Source: Statistics Austria (2009b); own calculations.

The useful surface area of the considered post war residential as well as public and private service buildings, defined as energy service (S) decreases by about 3% until 2020 compared to 2008, which reflects the demolition rate for the considered building stock. Useful energy intensity illustrates the change in heating demand in relation to the useful surface area (retrofitted and still to be retrofitted) of the considered building stock and achieves a reduction of about 29% until 2020 compared to 2008. Whereas overall energy demand decreases, the fuel mix is assumed to stay unchanged.

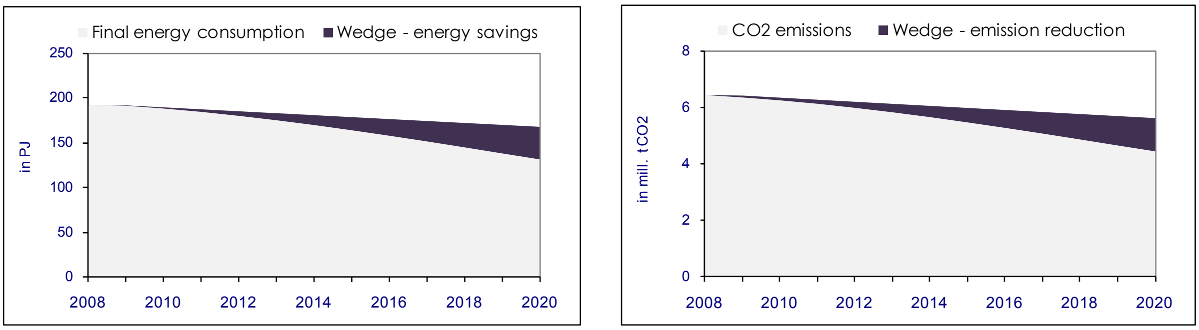
Figure 5.12: Technology Wedge B-1: Effects on final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. F is final energy consumption.

The change in final energy demand is depicted in Figure 5.13. Altogether, final energy demand is reduced by about 31% (from 192 PJ to 132 PJ) in 2020 compared to 2008 or, compared to the reference scenario, by 35 PJ (132 PJ in the technology wedge scenario compared to 167 PJ in the reference scenario).

Figure 5.13: Technology Wedge B-1: Effects on final energy consumption (left) and on CO_2 emissions (right)



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Simultaneously, Technology Wedge B-1 generates CO_2 emission reductions of 1.18 million t in 2020 compared to the reference scenario (4.42 million t CO_2 emissions in the technology wedge scenario compared to ca. 5.6 million t in the reference scenario, see Figure 5.13). Assuming that the decrease of electricity demand and heat demand in buildings in the technology wedge scenario will be fully achieved by a substitution of coal and gas power plants (for electricity) and gas heating plants (for heat production), another ca. 0.58 million t and respectively 0.31 million t CO_2 could be saved, compared to the reference scenario. A detailed description of the energy sector wedges is given in Part B, chapter 7.

Table 5.6: Technology Wedge B-1: Effects on final energy consumption and CO_2 emissions

Energy source	Final energy consumption				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Coal	2.80	1.93	-0.51	-21.0	0.27	0.19	-0.05	-21.0
Oil	50.02	34.46	-9.18	-21.0	3.90	2.69	-0.72	-21.0
Gas	40.80	28.11	-7.49	-21.0	2.24	1.55	-0.41	-21.0
Renewables	52.93	36.46	-9.72	-21.0	0.00	0.00	0.00	
Electricity	11.52	7.94	-2.12	-21.0	0.00	0.00	0.00	
Heat	33.76	23.26	-6.20	-21.0	0.00	0.00	0.00	
Total	**191.83**	**132.16**	**-35.22**	**-21.0**	**6.42**	**4.42**	**-1.18**	**-21.0**

Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Economic Aspects

The aim of the technology wedge is to reach a thermally improved building standard in all buildings to be retrofitted. Refurbishment of buildings is implemented according to at least low energy standard. Total investment costs for the refurbishment of relevant buildings in 2020 is about 6,034 million € compared 1,918 million € in 2008. The higher investment costs in 2020 result from an increased renovation rate and thus a larger area refurbished and a low energy standard. Accumulated, the investment costs amount to 55,682 million € for the period 2009 to 2020. The additional investment volume compared to a lower renovation rate and "standard" thermal quality (according to actual building code requirements) is about 4,826 million € in 2020 (accumulated ca. 38,985 million € between 2009 and 2020). In Table 5.7 the investment costs and operating costs of Technology Wedge B-1 are summarised. The investment costs contain the expenditures of a substantial retrofitting (renovation of the facades including replacement of windows, insulation of façades including base, roof/ceiling insulation, insulation of basement ceiling). The required data (specific investment costs per m² useful surface area, specific costs of energy saving, specific energy costs) are based on former analysis by the project team (see Kletzan-Slamanig et al., 2008). Table 5.8 displays the assumed development of specific additional investment costs of residential and non-residential buildings as calculated for LES refurbishment compared to a standard refurbishment (according building code) per m² useful surface area between 2008 and 2020.

Table 5.7: Development of specific additional investment costs for low energy standard (LES) refurbishment per m² useful surface area

Specific additional Inv estment costs - in €/m² (NES compared to BC)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Residential buildings													
S/DFH	130	127	125	122	120	118	115	113	111	108	106	104	102
MFH	60	59	58	56	55	54	53	52	51	50	49	48	47
Non-residential buildings	90	88	86	85	83	81	80	78	77	75	74	72	71

Source: Kletzan-Slamanig et al (2008). – LES – low energy standard, BC – building code, S/DFH – single/double family house, MFH – multi-family house.

Based on specific costs of 710 €/m² useful surface area for a LES refurbishment compared to 580 €/m² (according to standard refurbishment), a cost degression of about 2% p.a. is assumed. The material costs are assumed to decrease by 3% p.a., while labour costs are assumed to remain largely constant. With a cost ratio of about 60:40 (material vs. labour) the resulting average cost degression is about 2% p.a. The operating costs displayed in Table 5.8 are referring to the costs of the refurbished buildings only. The additional operating costs indicate the change of energy costs of LES refurbishment compared to a standard refurbishment In 2020 operating cost savings of 842 million € will be achieved.

Table 5.8: Technology Wedge B-1: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	2,261	2,688	3,218	3,883	4,272	4,717	5,227	5,478	5,739	6,012	6,153	6,034
Additional Costs	667	1,131	1,699	2,401	2,828	3,310	3,857	4,144	4,442	4,751	4,929	4,826
Operating costs	11	24	40	61	83	108	136	166	198	232	267	302
Additional Costs	-9	-29	-64	-116	-177	-250	-334	-424	-520	-623	-730	-835

Source: Kletzan-Slamanig et al (2008); own calculations.

The following two tables (Table 5.9 and Table 5.10) illustrate the disaggregation of the investment and the operating costs. The sectors construction work with structural and civil engineering, chemicals and chemical products, other non-metallic products, rubber and plastic products as well as wood and wood products are most strongly affected by investment in thermal refurbishment. The operating costs in the building sector basically consist of fuel costs (85%), further 10% of maintenance costs and 5% insurance.

Table 5.9: Technology Wedge B-1: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in total costs	Average share in investment costs in %	Average import share of good/service in %
Wood&wood prod.	5.0	1.5	5.0	1.5
Chemicals, chem. prod,	15.0	10.5	15.0	10.5
Rubber&plastic prod.	7.0	4.9	7.0	4.9
Other non-metallic prod.	10.0	2.0	10.0	2.0
Basic metals	3.0	2.1	3.0	2.1
Construction work				0.0
Structur,&civil engineer.	12.0	0.0	12.0	0.0
Build. installation, completion	45.0	0.0	45.0	0.0
Other services	3.0	0.0	3.0	0.0
Total	100.0	21.0	100.0	21.0

Source: Statistics Austria; own calculations.

Table 5.10: Technology Wedge B-1: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel costs	85	-95
Maintenance cost	10	-5
Insurance	5	0
Total	100	-100

Source: Own calculations.

Cost appraisal

For an integrated perspective of the investment and operating phase the service life of the technology represents a reasonable parameter for a breakdown of investment costs on a yearly basis (see also Part B, chapter 3 on the methodology for the microeconomic cost appraisal).

Table 5.11 summarises the cost appraisal for Technology Wedge B-1. For the calculation of the investment costs of residential and of non-residential buildings, a linear decrease in costs between 2008 and 2020, a service life of 40 years and an interest rate of 2.5% are assumed.

Specific investment costs for refurbishment are between 310 €/m² and 710 €/m² according to the different building categories and building standards. Operating costs are calculated based on the change in specific energy demand (between 117 kWh/m².a and 249 kWh/m².a compared to non-refurbished buildings and corresponding to the different building categories) and a constant energy price of the fuel mix (82 €/MWh). The user costs of capital range between 19.5 €/m².a and 35.5 €/m².a (in 2008). The total costs of refurbishment according to LES standard – resulting from investment and operating phase – are 38.9 €/m².a for single family residential buildings, 23.0 €/m².a for multi-family residential buildings, 36.8 €/m².a for public non-residential buildings and 36.7 €/m².a for private non-residential buildings in 2008. Compared to a standard refurbishment the additional investment costs per m² are about 5 - 10%. An integrated perspective of the investment and operating phase shows additional costs in 2020 between 3.1 €/m2.a (SFH) and 0.4 €/m2.a for public non-residential buildings.

Table 5.11: Cost appraisal of refurbishing buildings

Refurbishing buildings		Single family residential		Multy family residential		Public non-residential		Private non-residential	
		2008	2020	2008	2020	2008	2020	2008	2020
Investments									
Service life	years	40	40	40	40	40	40	40	40
Interest rate	% p.a.	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Investment price LES	€/m²	710.00	539.60	390.00	296.00	680.00	516.80	680.00	516.80
Investment price Standard	€/m²	580.00	440.80	310.00	235.28	590.00	448.40	590.00	448.40
Additional investment	€/m²	130.00	98.80	80.00	60.72	90.00	68.40	90.00	68.40
User cost of capital LES	€/m².a	35.50	26.98	19.50	14.80	34.00	25.84	34.00	25.84
User cost of capital Standard	€/m².a	29.00	22.04	15.50	11.76	29.50	22.42	29.50	22.42
User cost of capital additional invest.	**€/m².a**	**6.50**	**4.94**	**4.00**	**3.04**	**4.50**	**3.42**	**4.50**	**3.42**
Operating									
Energy flow non-refurbished	kWh/m².a	291.00	253.00	160.00	136.00	187.00	145.00	210.00	150.00
Energy flow LES	kWh/m².a	42.01	40.00	43.20	41.89	34.07	31.00	33.47	31.00
Energy flow Standard	kWh/m².a	64.02	62.00	64.02	61.00	70.07	68.00	69.47	67.00
Energy price (mix)	€/MWh	82.00	82.00	82.00	82.00	82.00	82.00	82.00	82.00
Energy costs non-refurbished	€/m².a	23.86	20.75	13.12	11.15	15.33	11.89	17.22	12.30
Energy costs LES	€/m².a	3.44	3.28	3.54	3.44	2.79	2.54	2.74	2.54
Energy costs Standard	€/m².a	5.25	5.08	5.25	5.00	5.75	5.58	5.70	5.49
Total									
Total Costs LES	€/m².a	38.94	30.26	23.04	18.24	36.79	28.38	36.74	28.38
Total Costs Standard	€/m².a	34.25	27.12	20.75	16.77	35.25	28.00	35.20	27.91
Additional costs	**€/m².a**	**4.70**	**3.14**	**2.29**	**1.47**	**1.55**	**0.39**	**1.55**	**0.47**

Source: Kletzan-Slamanig et al (2008); own calculations.

5.3.2 Technology Wedge B-2: Construction of new buildings according to Passive House Standard (PHS)

The technology wedge describes the accelerated penetration of new buildings until 2020 complying with passive house standard. The requirements of the new European Directive on Energy Performance in Buildings (EPBD 2010) for lowest and nearly zero energy buildings will be obligatory to all new constructed buildings in Europe from 2021 on. Based on the current new construction rate of ca. 1%, which will not substantially increase (from 1% in 2008 to just 1.2% in 2020) the building codes need to be significantly tightened by 2020. The building standard of new constructed buildings is assumed to gradually improve from low energy standard (specific heating demand 50 kWh/m².a) towards the passive house standard (<15 kWh/m².a). A penetration rate of passive house standard of about 90% of new buildings by 2020 is assumed for the residential sector as well as in the public building sector, while for private non-residential buildings PHS will be implemented at a slower rate (reaching 80% in 2020). Table 5.12 summarises the main assumptions and characteristics of Technology Wedge B-2.

Table 5.12: Summary Table for Technology Wedge B-2

Construction of new buildings according to Passive House Standard (PHS)	
New buildings according to Passive House Standard	Energy savings: up to 100 kWh/m².a for residential and 135 kWh/m² for non-residential buildings
Energy service	73.688 million m² useful surface area new constructed increasingly acc. PHS
Technology	Passive House Standard (PHS)
Required capacity increase*	Decrease of heating demand to < 15 kWh/m².a useful surface area
Diffusion path	Gradual
Total investment	6,924 million € in 2020, accumulated 47,051 million € by 2020 (additional costs of 1,086 million € in 2020, accumulated 7,457 million € by 2020 for new constructed buildings acc. to PHS compared to existing building code)[22]
Operating costs	74 million € in 2020
Emission reduction*	0.28 million t CO_2 in 2020

* Compared to the reference scenario.

Considering the required implementation of more efficient building codes (from LES to PHS for all newly constructed buildings) in Technology Wedge B-2 realises CO_2 emission reductions of 0.28 million t CO_2 in 2020 compared to the reference scenario.

[22] Total construction costs are considered in this wedge, while wedge B-1 considered only investment costs related to thermal refurbishment

Implementation of EnergyTransition methodology for Technology Wedge B-2

As Table 5.13 shows the total useful surface area in m² of new constructed residential as well as public and private service buildings, defined as energy service (S) will be about 19% higher in 2020 compared to 2008. This reflects the cumulated construction activity within the considered 12-year period. The useful energy intensity illustrates the change of the heating demand in relation to the new constructed useful surface area and reflects a reduction of about 16% of useful energy intensity of the new constructed building stock (mix of residential and non-residential construction activities) up to 2020 compared to 2008. Through the substantial improvement of the thermal building standard of the new buildings and the marginal remaining heating demand the fuel mix is also changing considerably between 2008 and 2020. In the new PHS buildings no fossil fuels will be used, the main share takes electricity (75%), the renewables share is ca. 20% and heat has a share of ca. 5%. Corresponding to the total building stock these fuel mix changes up to 2020 are only marginally visible in Table 5.13.

Table 5.13: Technology Wedge B-2: Summary of energy indicators

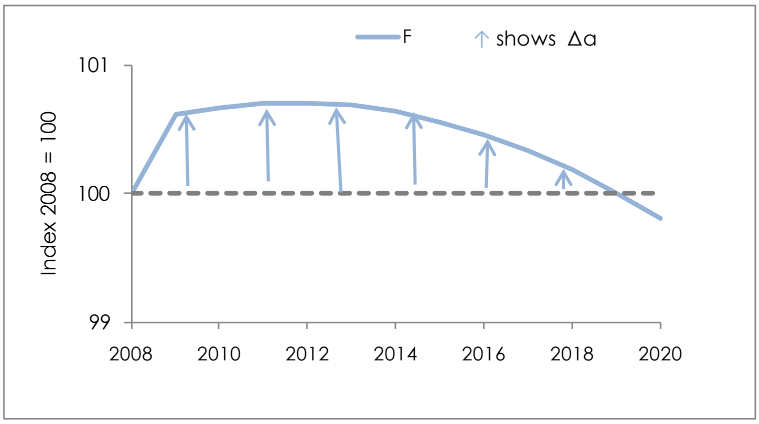
Space Heating - new building	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Services			
Energy Service	100	19	119
Energy intensities			
Useful Energy Intensity (u)	100	-16	84
Final Energy Intensity (f)	100	0	100
Final Energy (F)	100	0	100

Fuel Shift	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	1.5	-0.1	1.4
Oil	26.1	-0.1	25.9
Gas	21.3	-0.1	21.2
Renewables	27.6	-0.1	27.5
Electricity	6.0	0.5	6.5
Heat	17.6	-0.1	17.5
TOTAL	100.0	0.0	100.0

Source: Statistics Austria (2009b); own calculations.

Figure 5.14 demonstrates the development of indices according to the EnergyTransition methodology: The blue arrows illustrate the increase in energy demand due to a rise in energy services and despite declining useful energy intensity Δ(a) compared to 2008. Final energy intensity is assumed constant over time. The blue line thus shows the increase in final energy demand compared to 2008 driven by the assumed changes in service demand.

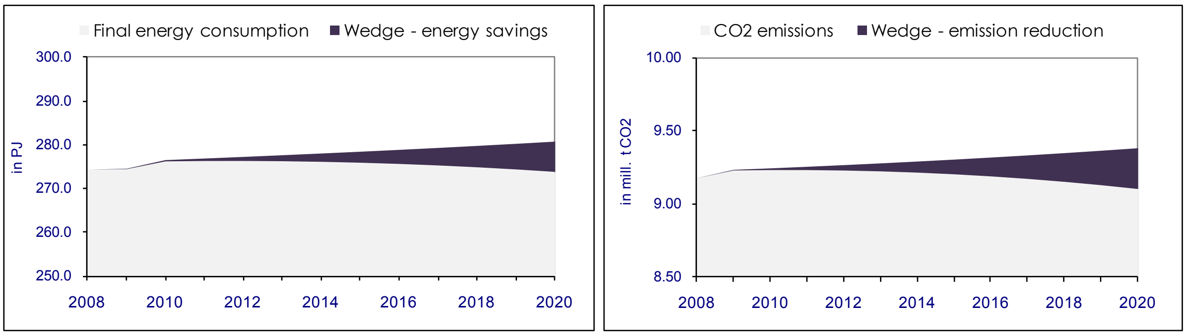
Figure 5.14: Technology Wedge B-2: Effects on final energy[1]



Source: Own illustration. - [1]Δa describes the combined effect of changes in energy services and useful energy intensity. F is final energy consumption.

The changes in final energy demand are shown in Figure 5.15. Final energy demand of newly constructed buildings will change from 100 to 99.8 between 2008 and 2020, representing the increase in the number of buildings, respectively the increase of useful surface area and continuous decrease of the energy intensity. Compared to the reference scenario the final energy consumption decreases by about 6.9 PJ from 280.7 PJ to about 273.9 PJ (2%) in 2020 in the technology wedge scenario by the substantially improved building standard.

Figure 5.15: Technology Wedge B-2: Effects on final energy consumption (left) and on CO_2 emissions (right)



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Technology Wedge B-2 generates CO_2 emission reductions of about 0.28 million t in 2020 compared to the reference scenario (9.1 million t CO_2 emissions in the technology wedge scenario compared to ca. 9.4 million t in the reference scenario (see Figure 5.15)) generated by the penetration of PHS of buildings.

Assuming that the decrease of electricity demand and heat demand in buildings in the technology wedge scenario will be fully achieved by a substitution of coal and gas power plants (for electricity) and gas heating plants (for heat production), another ca. 0.18 million t respectively 0.14 million t CO_2 could be saved, compared to the reference scenario. For detailed description of the effects on energy sector see Part B, chapter 7.

Table 5.14: Technology Wedge B-2: Effects on final energy consumption and CO_2 emissions

Energy source	Final energy consumption				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Coal	4.00	3.80	0.0	0.0	0.39	0.37	0.0	0.0
Oil	71.54	71.05	-2.3	-3.1	5.58	5.54	-0.2	-3.1
Gas	58.35	58.04	-1.9	-3.2	3.21	3.19	-0.1	-3.2
Renewables	75.70	75.37	-2.1	-2.7	0.0	0.0	0.0	0.0
Electricity	16.48	17.70	0.9	5.1	0.0	0.0	0.0	0.0
Heat	48.29	47.89	-1.5	-3.0	0.0	0.0	0.0	0.0
Total	**274.4**	**273.85**	**-6.85**	**-2.4**	**9.18**	**9.10**	**-0.28**	**-3.0**

Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Economic Aspects

The main assumption for the technology wedge is a thermally improved building standard for all new buildings. New buildings will increasingly be constructed according to passive house standard. The total investment costs for the whole new construction of the relevant residential and non-residential buildings is about 6,924 million € in 2020 (compared 763 million € in 2009) and accumulated 47,051 million € between 2009 and 2020. The additional total investment volume compared to "standard" new buildings (according to current building code requirements) has been calculated to amount to 1,086 million € in 2020 (accumulated ca. 7,457 million € between 2009 and 2020). In Table 5.15, the investment costs and operating costs of Technology Wedge B-2 are summarised. The investment costs contain the expenditures for new buildings according to the assumed construction rate of about 1% to 1.2% p.a. of the useful surface area. The required data for new buildings (specific investment costs per m² useful surface area, specific costs of energy saving, specific energy costs) are based on former analysis by the project team (see Kletzan-Slamanig et al., 2008) and on BKI (2007 and 2010)[23]. Furthermore, a cost decrease of about 2% p.a. is considered (see also chapter 5.3.1). Comparing the increase of PHS buildings and the simultaneous reduction of LES buildings operating cost savings of 124 million € can be realised in 2020.

[23] Specific costs of 1,600 €/m² useful surface area for S/DFH and 1,200 €/m² useful surface area for new constructed residential buildings as well as 2,050 €/m² useful surface area for new constructed non-residential in PHS are the basis for the calculations.

Table 5.15: Technology Wedge B-2: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	763	1,369	1,965	2,550	3,125	3,688	4,239	4,795	5,343	5,881	6,409	6,924
Additional Costs	121	219	314	408	499	589	676	762	846	929	1,008	1,086
Operating costs	1	3	6	9	14	19	26	33	42	51	62	74
Additional Costs	-2	-5	-10	-17	-25	-35	-46	-58	-72	-88	-105	-124

Source: Statistics Austria; own calculations.

The following two tables show the disaggregation of investment and operating costs. The sectors construction with structural and civil engineering, chemicals and chemical products, other non-metallic products, rubber and plastic products as well as wood and wood products are most strongly affected by the investment in new buildings. The operating costs in the building sector basically consist of fuel costs (85%), further 10% of maintenance costs and 5% insurance.

Table 5.16: Technology Wedge B-2: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Wood&wood prod.	5.0	1.5	5.0	1.5
Chemicals, chem. prod,	15.0	10.5	15.0	10.5
Rubber&plastic prod.	7.0	4.9	7.0	4.9
Other non-metallic prod.	10.0	2.0	10.0	2.0
basic metals	3.0	2.1	3.0	2.1
Construction work	60.0	0.0	60.0	0.0
Total	100.0	21.0	100.0	21.0

Source: Statistics Austria; own calculations.

Table 5.17: Technology Wedge B-2: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel costs	85	-95
Maintenance cost	10	-5
Insurance	5	0
Total	100	-100

Source: Own calculations.

Cost appraisal

For the calculation of new constructed buildings the investment costs of passive house standard for the different building categories and a service life of 40 years are used. The user costs of capital are calculated with an interest rate of 2.5%.

Specific investment costs per m² new constructed passive buildings are between 1,200 €/m² and 1,600 €/m² for residential buildings and 2,050 €/m² for non-residential buildings. The operating costs are calculated for an energy demand of 15 kWh/m².a and a constant energy price of 145 €/MWh of PHS buildings, which represents a change in the energy mix in favour of electricity (for operation of controlled ventilation system and heat pump) and an almost diminishing remaining heat demand from conventional sources. The user costs of capital of new constructed passive houses range between 60.0 €/m².a and 102.5 €/m².a for the different building categories. The total annual costs (investment and operating costs) of new constructed PHS buildings are between 62.2 €/m².a and 104.7 €/m².a. The additional investment costs per m² of about 1 - 5% for residential buildings and 20% for non-residential buildings are compared with savings of energy costs of about 4 - 7 €/m².a.

Table 5.18: Cost appraisal of new buildings

New building PHS		Single family residential		Multy family residential		Public non-residential		Private non-residential	
		2008	2020	2008	2020	2008	2020	2008	2020
Investments									
Service life	years	40	40	40	40	40	40	40	40
Interest rate	% p.a.	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Investment price PHS	€/m²	1600.00	1216.00	1200.00	912.00	2050.00	1558.00	2050.00	1558.00
Investment price LES	€/m²	1450.00	1102.00	1110.00	843.60	1550.00	1178.00	1550.00	1178.00
User cost of capital PHS	€/m².a	*80.00*	*60.80*	*60.00*	*45.60*	*102.50*	*77.90*	*102.50*	*77.90*
User cost of capital LES	**€/m².a**	***72.50***	***55.10***	***55.50***	***42.18***	***77.50***	***58.90***	***77.50***	***58.90***
Operating									
Energy flow PHS	kWh/m².a	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Energy flow LES	kWh/m².a	70.00	60.90	70.00	60.90	70.00	60.90	107.84	93.82
Energy price (mix) PHS	€/MWh	145.00	145.00	145.00	145.00	145.00	145.00	145.00	145.00
Energy price (mix) LES	€/MWh	82.00	82.00	82.00	82.00	82.00	82.00	82.00	82.00
Energy costs PHS	€/m².a	*2.18*	*2.18*	*2.18*	*2.18*	*2.18*	*2.18*	*2.18*	*2.18*
Energy costs LES	€/m².a	5.74	4.99	5.74	4.99	5.74	4.99	8.84	7.69
Total									
Total Costs PHS	€/m².a	*82.18*	*62.98*	*62.18*	*47.78*	*104.68*	*80.08*	*104.68*	*80.08*
Total Costs LES	€/m².a	*78.24*	*60.09*	*61.24*	*47.17*	*83.24*	*63.89*	*86.34*	*66.59*
Additional costs	**€/m².a**	***3.94***	***2.88***	***0.93***	***0.60***	***21.44***	***16.18***	***18.33***	***13.48***

Source: Kletzan-Slamanig et al (2008); BKI Baukosten2007 and 2010, own calculations.

5.3.3 Technology Wedge B-3a: Replacement of heating systems by more efficient systems based on renewables

This technology wedge considers the heating systems of residential buildings of the construction periods 1900 -1990.

Most installed heating systems are rather inefficient. Especially in the household sector the requirement to replace old and inefficient heating systems to gain energy savings through user-optimised systems is acknowledged. Starting from the current heating system stock of about 2.7 million heating systems in the residential area[24] the replacement rate of heating

[24] Underlying are beside the energy statistic data also statistic data of several heating plants, evaluated by associations and authorities, e.g. evaluation of biomass plants by Landwirtschaftskammer Niederösterreich (2006), of pellet plants by "pro pellets Austria" (2009), of heat pumps by BMVIT (2008 and 2009).

systems rises from 2% of the stock in 2008 to 4% in 2020. The replacement is ideally combined with a comprehensive building refurbishment (following assumptions made in Technology Wedge B-1).

The assumption for Technology Wedge B-3a is that the energy intensity of new efficient heating systems in single and multi-family houses can be reduced by an average of 10% through new technologies and optimised regulation and control. Furthermore, a continuous switch from fossil fuel-based systems to renewables is assumed in this technology wedge, together with a significantly lower total heat demand in absolute terms (due to an increase of the penetration rate of LES in the building stock and new buildings constructed according to PH standard). A potential change of the fuel mix of heating systems is demonstrated in Table 5.19 (based on shares in useful energy demand). It has to be noted that heating systems in non-residential buildings cannot be considered here, due to a lack of data on the types of heating systems in use.

Table 5.19: Change of energy mix 2008/2020 for heating (useful energy demand))

Share of fuel sources in useful energy demand	2008	2020
coal	1.7%	0.9%
oil	28.9%	20.3%
gas	19.9%	15.0%
renewables	33.4%	44.4%
electricity	4.1%	1.6%
district heating	11.9%	17.9%
total	**100.0%**	**100.0%**

Source: Statistics Austria, Landwirtschaftskammer Niederösterreich (2006), pro pellets (2009), BMVIT (2008/2009); own calculations.

The main assumptions and characteristics of the technology wedge are summarised in Table 5.19. Technology Wedge B-3a covers the replacement of outdated heating systems in residential buildings by more efficient systems based on renewable energy sources, e.g. biomass, like fuel wood, pellets, wood chips as well as heat pumps. Solar heat used for space heating is considered separately in chapter 5.3.4. District heating plants are generally working on both, fossil fuels as well as renewables, e.g. biomass (in the statistical data of district heating double counting cannot be excluded). But the focus here is on the substitution of fossil fuels by renewables.

Table 5.20: Summary Table for Technology Wedge B-3a

Replacement of heating systems by more efficient systems	
Replacement of heating systems	Replacement of heating systems by more efficient systems based on renewables in residential buildings
Energy service	Heated useful surface area of residential buildings (1900 – 1990), 163 million m²
Technology	More efficient low temperature heating plants, improved efficiency (10%) and shift to renewables
Required capacity increase*	Replacement of heating systems of yearly 2% (2008) increasing to 4% (by 2020), approx. 891,700 heating systems are replaced by 2020
Diffusion path	Linear
Total investment	Accumulated investment of 10,191 million € by 2020, 912 million € in 2020 (accumulated additional cost 2,480 million € compared to ref. scenario)
Operating costs	1,927 million € in 2020
Emission reduction*	2.1 million t CO_2 in 2020

* Compared to the reference scenario.

With the annual replacement rate rising from 2% in 2008 up to about 4% in 2020 about 891,700 heating systems (mainly combined with building refurbishments according to low energy standard) will be replaced by highly efficient ones. Simultaneously, with the replacement of the heating systems the heat demand diminishes due to the increasingly improved thermal quality of the residential buildings.

Implementation of EnergyTransition methodology for Technology Wedge B-3a

Table 5.21 summarises the changes in energy indicators for Technology Wedge B-3a heating systems.

The useful surface area which is heated by different heating systems and energy sources is defined as the energy service (S). The decrease of S by about 5% up to 2020 is reflecting the demolition rate of the building stock considered for replacement of heating systems (residential buildings of the construction period 1900 – 1990). The useful energy intensity remains at a constant level, whereas the final energy intensity reflects the improvement of the efficiency of the heating systems by about 10% in total. Furthermore, the shift from fossil-based heating systems to renewables and district heating is shown (see also Table 5.19).

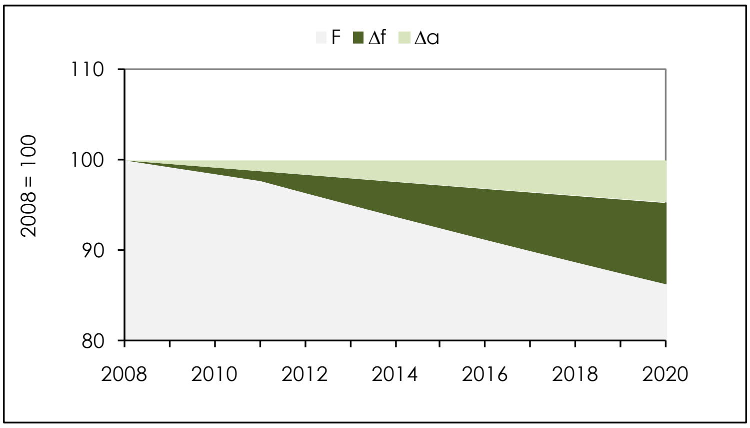
Table 5.21: Technology Wedge B-3a: Summary of energy indicators

Heating Refurbishment & Fuel Switch	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Services			
Energy Service	100	-5	95
Energy intensities			
Useful Energy Intensity (u)	100	0	100
Final Energy Intensity (f)	100	-9	91
Final Energy (F)	100	-14	86

Fuel Shift	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	1.7	-0.8	0.9
Oil	28.9	-8.7	20.2
Gas	19.9	-5.0	14.9
Renewables	33.4	11.0	44.4
Electricity	4.1	-2.4	1.6
Heat	11.9	6.0	17.9
TOTAL	100.0	0.0	100.0

Source: Statistics Austria; own calculations.

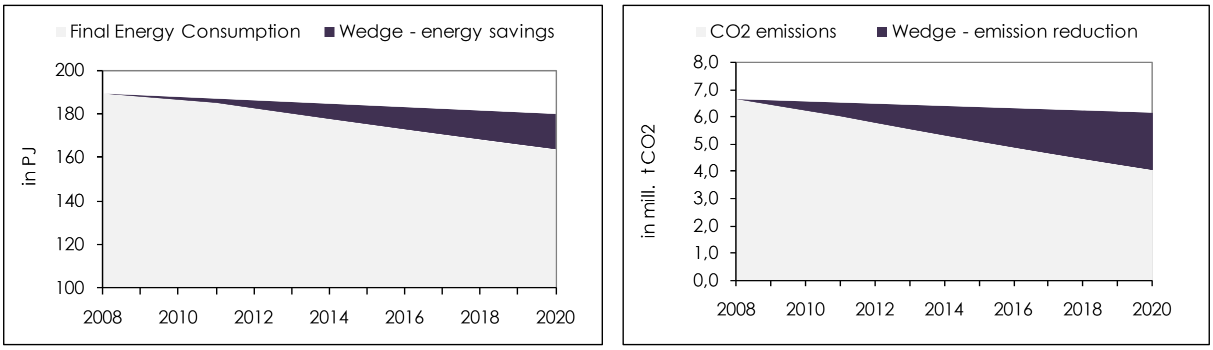
Figure 5.16: Technology Wedge B-3a: Effects on useful energy and final energy[1]



Source: Own illustration. . – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. Useful energy is the sum of F and Δf.

The change in final energy demand is demonstrated in Figure 5.17. The demand is reduced by about 14% (from 189 PJ to 164 PJ) compared to 2008, and compared to the reference scenario by about 9% (164 PJ in the technology wedge scenario compared to 180 PJ in the reference scenario).

Figure 5.17: Technology Wedge B-3a: Effects on final energy consumption (left) and on CO_2 emissions (right)



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Technology Wedge B-3a 'Heating systems' generates CO_2 emission reductions of about 2.1 million t in 2020 compared to the reference scenario (4.07 million t CO_2 emission in the technology wedge scenario compared to ca. 6.17 million t in the reference scenario, see Figure 5.17).

Assuming that the decrease of electricity demand and heat demand in buildings in the technology wedge scenario will be fully achieved by a substitution of coal and gas power plants (for electricity) and gas heating plants (for heat production), ca. 0.96 million t and additionally 0.63 million t CO_2 (if district heat will be supplied by gas heating plants) could be saved, compared to the reference scenario. In the case that district heat will be supplied by biomass heating plants no additional emissions are caused. For a detailed description of the effects on the energy sector see Part B, chapter 7.

Table 5.22: Technology Wedge B-3a: Effects on final energy consumption and CO_2 emissions

Energy source	Final energy consumption				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Coal	3.3	1.4	-1.9	-56.4	0.3	0.14	-0.2	-56.3
Oil	54.8	33.1	-17.6	-34.8	4.3	2.58	-1.4	-34.8
Gas	37.8	24.5	-9.9	-28.8	2.1	1.34	-0.5	-28.8
Renewables	63.4	72.6	10.9	17.7	0.0	0.0		
Electricity	7.7	2.7	-4.6	-63.6	0.0	0.0		
Heat	22.6	29.3	6.7	29.8	0.0	0.0		
Total	**189.5**	**163.6**	**-16.4**	**-9.1**	**6.7**	**4.1**	**-2.1**	**-34.1**

Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Economic Aspects

The main change in the technology wedge is the use of more efficient heating systems on the basis of renewable energy sources in residential buildings combined with a total heat demand reduction through thermally improved buildings. The additional investment volume compared to the reference scenario, where the replacement of heating systems remains constant at 2% per year and is implemented at a slower rate, has been calculated at about 270 million € in 2020 (accumulated ca. 2,480 million € between 2009 and 2020). Total investment costs for the replacement of heating systems in residential buildings are about 912 million € in 2020 (compared to 2009 662 million €) and accumulated 10,191 million € for the period 2009 to 2020. In Figure 5.23 the investment costs and operating costs of Technology Wedge B-3a 'Heating systems' are summarised. The investment costs contain the expenditure for the heating system and the installation costs. Average system costs for S/DFH were estimated to about 18,770 €/system and for MFH to 33,650 €/system (see Kletzan-Slamanig et al., 2008). Compared to the reference scenario operating cost savings of 421 million € can be generated in 2020.

Table 5.23: Technology Wedge B-3a: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	662	673	738	780	833	881	930	971	948	938	926	912
Additional Costs	19	30	96	138	191	238	288	328	305	295	283	270
Operating costs	99	205	325	457	603	763	940	1,131	1,323	1,519	1,720	1,927
Additional Costs	-13	-29	-48	-71	-98	-130	-168	-211	-257	-307	-362	-421

Source: Statistics Austria; own calculations.

The following two tables demonstrate the disaggregation of the investment and the operating costs. The sector rubber & plastic products, metal products, building installation and precision instruments are most strongly affected by the investment in replacement of heating plants. The operating costs basically consist of fuel costs (85%), further 13% of maintenance cost and personnel costs and 2% insurance.

Table 5.24: Technology Wedge B-3a: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Rubber&plastic products	7	3.5	7	3.5
Metal products	70	21	70	21
Other non-metallic prod.	3	0.6	3	0.6
Building installation	12	1.2	12	1.2
Precision instruments	8	0.4	8	0.4
Total	100	27	100	27

Source: Statistics Austria; own calculations.

Table 5.25: Technology Wedge B-3a: Disaggregation of operating costs

Category	Av erage share in total operating costs in %	Av erage share in additional oc in %
Fuel costs	85	-95
Serv ice and Maintenance cost	13	-5
Insurance	2	0
Total	100	-100

Source: Statistics Austria; own calculations.

Cost appraisal

Based on data for the investment and the operating phase the microeconomic costs are analysed. For the calculation of the replacement of heating system investment costs per m² heated useful surface for single family and for multi-family residential buildings and a service life of 20 years are used. The user costs of capital are calculated with an interest rate of 2.5%.

Average heating system costs are assumed[25]. Relating to useful heat per system specific user costs of capital are calculated: 63.9 €/MWh.a for single family residential and 114.5 €/MWh.a for multi-family residential buildings. Operating costs refer to a weighted energy price of (energy mix) 82 €/MWh in 2008 and 90.5 €/MWh in 2020. Total costs of replaced heating systems amount to 146 €/MWh.a for single family residential buildings and 196.6 €/MWh.a for multi-family residential buildings (2008).

Table 5.26: Cost appraisal of replacement of heating systems

Heating systems		**Single family house**		**Multi-family house**	
		2008	**2020**	**2008**	**2020**
Investments					
Serv ice life	years	20	20	20	20
Interest rate	% p.a.	2.5	2.5	2.5	2.5
Inv estment price	€/m²	197.58	197.58	60.09	60.09
User cost of capital	***€/MWh.a***	***63.85***	***46.25***	***114.47***	***82.91***
Operating					
Energy price (mix)	€/MWh.a	82.13	90.45	82.13	90.45
Total costs	***€/MWh.a***	***145.98***	***136.70***	***196.60***	***173.36***
Reference price for heat	***€/MWh***	***50.00***	***50.00***	***50.00***	***50.00***

Source: Kletzan-Slamanig et al (2008) and own calculations

[25] 18,770 € for single family residential buildings, 33,650 € for multi-family residential buildings following Kletzan-Slamanig et al (2008) and own calculations

5.3.4 Technology Wedge B-3b: Solar heat for space heating and hot water generation

In addition to the replacement of inefficient heating systems solar energy plays a significant role in space heating. While in the past solar water heating found widespread use in new buildings especially in single/double family houses, solar heat for space heating is only slowly accepted. But increasingly large solar heating plants for multi-family houses as well as solar integration in district heating systems are used.

According to ESTTP (2008) the unique and specific benefits of solar thermal energy are:

- Solar thermal always leads to a direct reduction of primary energy consumption.
- Solar thermal can be combined with nearly all kinds of back-up heat sources.
- Solar thermal has the highest potential among the renewable heating and cooling technologies and does not rely on finite resources, needed also for other energy and non-energy purposes.
- Solar thermal does not lead to a significant increase in electricity demand, which could imply substantial investments to increase power generation and transmission capacities.
- Solar thermal is available nearly everywhere. Current limitations, for instance at very high latitudes or in case of limited space for heat storage, can be largely overcome through R&D.
- Solar thermal energy prices are highly predictable, since the largest part of them occur at the moment of investment, and therefore does not depend on future oil, gas, biomass, or electricity prices.
- The life-cycle environmental impact of solar thermal systems is low.
- Solar thermal replaces like other renewable and locally available sources (mainly imported) fossil sources and creates local jobs. Wherever the solar thermal energy hardware will be produced in the future, a large portion of the value chain (distribution, planning, installation, maintenance) is inherently related to the demand side.

Solar thermal is therefore an excellent option for covering the long-term heating and cooling demand. In the long-term the goal will be to meet heating demand as far as technically possible with solar energy; while electricity, biomass and fossil fuel resources are used in cases where solar heating is not (yet) available at acceptable costs.

Technology Wedge B-3b ‘Solar heating’ covers the intensified use of solar energy for space heating and hot water generation in residential buildings and non-residential service buildings. Starting from the level of about 3.6 million m² installed collector area in 2007/2008 (see BMLFUW, 2008) and 4.3 million m² in 2009 (see BMVIT, 2010a) and a solar coverage rate of currently about 1% of the Austrian low temperature demand (< 250 °C) the coverage rate is expected to increase to 10% up to 2020. Assumed is a decrease of total low temperature demand in the residential, commercial and service sectors in the same period of about 16% (less heating and hot water demand due to changes described in the technology wedges above). Until 2020, 26.77 million m² solar collector area should be installed and cover approx. 10% of the forecasted energy demand (ca. 29.4 PJ according to the trend of the useful energy analyses 2009b). The main assumptions and characteristics of the technology wedge are summarised in Table 5.27.

Table 5.27: Summary Table for Technology Wedge B-3b

Solar heating	
Forced use of solar heating	Intensified increase of solar heat for space heating and hot water in residential and non-residential buildings, from 2.7 PJ (2008) to 29.4 PJ solar heat (2020)
Energy service	Solar heated useful surface area of residential and non-residential buildings, total about 320 million m²
Technology	26.77 million m² solar collector area installed by 2020 (23.2 million m² additionally based 2008) - mostly flat plate and tube collectors
Required capacity increase*	18.42 million m² additional solar collector area compared to reference scenario
Diffusion path	Linear
Total investment	Accumulated 14,294 million € by 2020 (accumulated additional cost 11,447 million € compared to reference scenario)
Operating costs	669 million € in 2020
Emission reduction*	0.34 million t CO_2 by 2020

* Compared to the reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge B-3b

The energy service (S) is expressed as the useful surface area of residential and non-residential buildings (public and private service buildings) heated by solar energy. Considered are the useful surface areas of residential buildings in line with Technology Wedge B-3a replacement of outdated heating systems[26] and of non-residential buildings according Technology Wedge B-1 'renovation'. It is assumed that the additional potential for this building period is the highest whereas in newly constructed buildings solar heating is used in any case. Thus it is assured that double counting will be avoided.

Heat is produced by solar collectors, mostly flat plate and tube collectors. Starting from 3.6 million m² installed collector area in 2008 enormous efforts are required in the next ten years to achieve the increase to 26.77 million m² up to 2020. In the reference scenario a yearly increase of about 7% and an installed collector area of 8.35 million m² in 2020 are assumed.

Solar collectors are installed on roofs of residential buildings (S/DFH and MFH) as well as on roofs of non-residential buildings, e.g. public service buildings (administrative buildings, schools, etc.) and private service buildings (office buildings, hotels, whole and retail sale

[26] Considering the building construction period from 1900-1990.

buildings etc.). In addition to roofs, solar collectors will be integrated in the building facades. Solar heating is increasingly used in the course of building refurbishment, hence multifunctional facades will play an important role in the future. They combine the functionality of the state of the art components (statics, weather protection, fire protection) with the ability to meet the energy requirements of buildings. Table 5.28 summarises the assumed changes in the variables for Technology Wedge B-3b.

Table 5.28: Technology Wedge B-3b: Summary of energy indicators

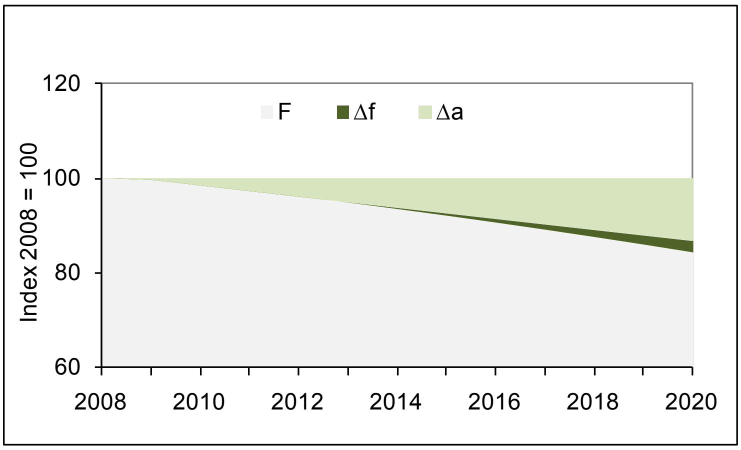
Solar Heating	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Services			
Energy Service	100	-3	97
Energy intensities			
Useful Energy Intensity (u)	100	-10	90
Final Energy Intensity (f)	100	-3	97
Final Energy (F)	100	-16	84

Fuel Shift	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	1.5	-0.1	1.4
Oil	26.1	-1.7	24.4
Gas	21.3	-1.5	19.8
Renewables	27.6	2.9	30.5
Electricity	6.0	0.1	6.1
Heat	17.6	0.2	17.8
TOTAL	100.0	0.0	100.0

Source: BMLFUW (2008), BMVIT (2010); own calculations.

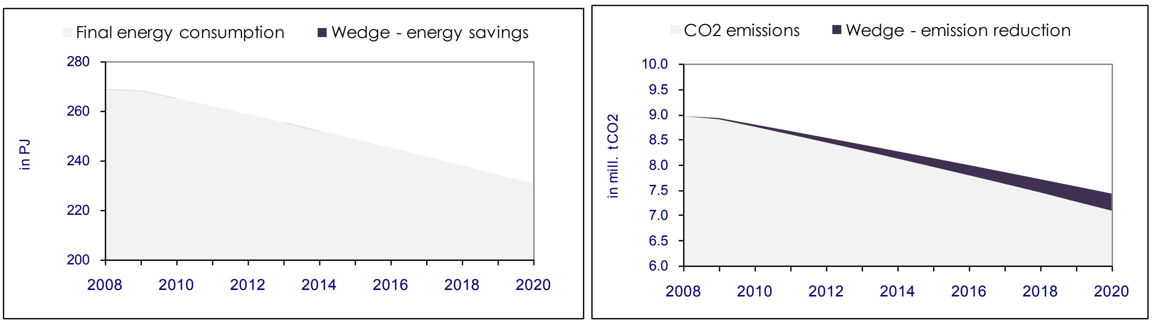
Solar heated useful surface area of residential and non-residential buildings (S) decreases in line with the building area of Technology Wedge B-1 renovation and of B-3a heating systems by about 3% in 2020 (compared to 2008). The decrease reflects the demolition rate of the considered building stock, see also chapter 5.3.1. Table 5.28 visualises the increased efficiency, i.e. useful energy intensity (u) decreases by about 10% and final energy intensity (f) by 3%. Final energy (F) decreases by about 16% between 2008 and 2020. The penetration of solar systems between 2008 and 2020 is reflected in the reduction of fossil fuels (coal, oil and gas) by 3.2% and the increase of renewables by 2.9%.

Figure 5.18: Technology Wedge B-3b: Development of final energy and useful energy[1]



Source: Own illustration. [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is the sum of F and Δf.

Figure 5.19: Technology Wedge B-3b: Effects on final energy consumption (left) and on CO_2 emissions (right)



Source: Statistics Austria (2009b), UNFCCC (2010); own calculations. – [1] The decrease in final energy consumption as depicted in the Figure results mainly from the decrease in energy services due to demolition of the building stock as well as a moderate improvement of efficiency of the heating systems considered in this technology wedge. Solar heating per se contributes only 4 PJ to the decrease in energy consumption.

Table 5.19 shows the change of final energy demand supplied through solar heating systems, which will in total decrease by about 41.7 PJ in the technology wedge between 2008 and 2020 and 3,5 PJ compared to the reference scenario in 2020.

Technology Wedge B-3b solar heating generates CO_2 emission reductions of 0.34 million t CO_2 in 2020 compared to the reference scenario (7.1 million t CO_2 emissions in 2020 in the wedge scenario compared ca. 7.44 million t CO_2 in the reference scenario, see Figure 5.19). The kink in the year 2008 and 2009 visualises the decrease of useful energy from 2008 to 2009 in the sector space heating and air conditioning of households (189.5 PJ to 186.8 PJ) and of other services (84.9 PJ to 83 PJ), caused by changed consumer behaviour during this period, while in the following years a slight rise is assumed to take place.

Assuming that the decrease of electricity demand and heat demand in buildings in the technology wedge will be fully achieved by a substitution of coal and gas power plants (for electricity) and gas heating plants (for heat production), another ca. 0.05 million t and respectively 0.2 million t CO_2 could be saved, compared to the reference scenario. A detailed description of the effects on the energy sector is provided in Part B, chapter 7.

Table 5.29: Technology Wedge B-3b: Effects on final energy consumption and CO_2 emissions

Energy source	Final energy consumption				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Coal	3.92	3.18	-0.25	-7.2	0.38	0.309	-0.02	-7.2
Oil	70.07	55.37	-2.49	-4.3	5.47	4.319	-0.19	-4.3
Gas	57.15	44.94	-2.23	-4.7	3.14	2.471	-0.12	-4.7
Renewables	74.14	69.14	3.81	5.8	0.0	0.0		
Electricity	16.14	13.95	-0.22	-1.5	0.0	0.0		
Heat	47.29	40.44	-2.17	-5.1	0.0	0.0		
Total	**268.7**	**227.0**	**-3.5**	**-1.5**	**9.0**	**7.1**	**-0.34**	**-4.6**

Source: Statistics Austria (2009b), UNFCCC (2010); own calculations.

Economic Aspects

The inclusion of solar heating components in both residential and non-residential service buildings up to 2020 requires significant investment in the next few years. Based on average system costs of about 750 €/m² collector area (see also BMLFUW, 2008) an additional investment volume for the solar heat wedge has been calculated to amount to 773 million € in 2020 (accumulated ca. 11,447 million € between 2009 and 2020) compared to a reference path. Further cost degression is to be expected and is assumed to reach 3% in 2020. Total investment costs are about 1,048 million € in 2020 (compared to 274 million € in 2009) and accumulated 14,294 million € until 2020. Table 5.30 summarises the investment volume and the operating costs of Technology Wedge B-3b 'Solar heating'. The investment costs include the system expenditure for solar heating and supplementary installation. Operating costs mainly consist of service and maintenance costs and marginal expenditures like electricity costs (for pumping) etc. Operating costs amount to 669 million € in 2020. Compared to a reference path operating cost savings of 428 million € can be realised in 2020.

Table 5.30: Technology Wedge B-3b: Development of investment and operating costs (in million €)

in m €	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	274	1,500	1,461	1,415	1,368	1,321	1,275	1,228	1,181	1,135	1,088	1,048
Additional Costs	55	1,298	1,252	1,198	1,144	1,089	1,035	981	927	874	820	773
Operating costs	81	126	172	220	270	322	376	431	488	546	607	669
Additional Costs	-52	-80	-110	-141	-173	-206	-240	-276	-312	-350	-388	-428

Source: BMLFUW (2008), BMVIT (2010); own calculations.

Table 5.31 and Table 5.32 illustrate the disaggregation of the investment and operating costs. Due to the cost structure the sectors rubber and plastic products, fabricated metal products, building installation and building completion as well as precision instruments are most strongly affected by the investment in solar heating.

Table 5.31: Technology Wedge B-3b: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Rubber&plastic product	40	12	40	12
Metal products	30	6	30	6
Building installation	20	2	20	2
Precision instruments	10	0.5	10	0.5
Total	100	21	100	21

Source: Statistics Austria; own calculations.

The operating costs are split in service and maintenance costs (80%), insurance (15%), and electricity costs (1.5%) and in case of modernisation of recycling costs (3.5%).

Table 5.32: Technology Wedge B-3b: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Service & maintenance costs	80.0	-90.0
Insurance	15.0	-5.0
Electricity costs	1.5	-5.0
Recycling costs	3.5	0.0
Total	100.0	-100.0

Source: Own calculations.

Cost appraisal

For Technology Wedge B-3b the specific annual heat generation costs are analysed based on the data for the investment and the operating phase. For the calculation of solar heating the investment costs (average system costs of 750 €/m² collector area) for all building categories, a service life of 25 years and an interest rate of 2.5% are assumed.

For the operating costs in 2008 heat generation of 400 kWh/m².a and an energy price of 82 €/MWh are presumed. The user costs of capital amount to 122 €/MWh.a (2008) and 65.3 €/MWh.a (2020). Total costs of solar heating (annualised investment and operating costs) are 171.9 €/MWh.a (2008) and 115.3 €/MWh.a (2020), respectively.

Table 5.33: *Cost appraisal of solar heating*

Solar heating		Residential & non-residential	
		2008	2020
Investments			
Service life	years	25	25
Interest rate	% p.a.	2.5	2.5
Investment price	€/m²solar	750.00	750.00
User cost of capital	**€/MWh.a**	***121.90***	***65.30***
Operating			
Operating costs	€/MWh.a	50.00	50.00
Total costs	**€/MWh.a**	***171.90***	***115.30***
Reference price for heat	**€/MWh**	***50.00***	***50.00***

Source: BMLFUW (2008), BMVIT (2010); own calculations

5.3.5 Technology Wedge B-4: Increased power production of buildings for own consumption – example photovoltaic energy

According to the requirements of the new Energy Performance of Buildings Directive (EPBD) 2010, zero energy buildings will gain in importance during the next years. As the heat demand in thermally improved buildings in the future will be very low or close to zero, electricity demand will become the most relevant option for further optimisation. Therefore, potentials for auto electricity production are to be considered, such as solar electricity (photovoltaics), or electricity production from small combined heat and power systems (micro-CHPs), small wind power plants or other upcoming technologies.

Technology Wedge B-4 focuses on one example of such technologies, namely the enforced use of photovoltaic for power production of buildings for own consumption. Combined with measures for building refurbishment and/or new construction existing roofs will be increasingly equipped with photovoltaic panels.

The assumption is that the penetration rate of S/DFH equipped with 5 kW_p photovoltaic panels per building and MFH as well as public and private service buildings equipped with 10 kW_p panels per building will significantly rise during the next decade. The required roof space is currently on average 10 m² per installed 1 kW_p. Beside the roofs, photovoltaic panels are suitable to be installed in building facades. Currently, 25% of the PV panels are installed on facades in Austria, with a significant potential in the future for different applications in the building envelope. The potential is huge, simply because of a very low installed capacity so far (ca. 32.4 MW_p installed photovoltaic panels in 2008 that produce about 0.11 PJ, which is only ca. 0.1% of current electricity demand in the household and service sectors). By 2020, it is planned to install 354 MW_p (see BMVIT, 2008). At an average of 900 full load hours per year about 1.29 PJ (ca. 1.1% of the expected demand in that year) could be realised by 2020. The growth rate assumed (about 22% p.a. on average between 2010 and 2020), correspond more or less to the targets formulated in the PV Roadmap for Austria (see also "Perspectives for 2050", Part B, chapter 10). The main assumptions and characteristics of the technology wedge are summarised in Table 5.34.

Table 5.34: Summary Table for Technology Wedge B-4

Increased power production of buildings for own consumption	
Increased power production for own consumption	Roofs of refurbished and new buildings will be equipped with photovoltaic panels.
Energy service	Residential buildings and non-residential buildings, using electricity for different purposes
Technology	354 MWp photovoltaic panels are installed by 2020
Required capacity increase*	Increase from 32 MWp (2008) to 354 MWp in 2020, compared to 130 MWp (reference scenario)
Diffusion path	Linear
Total investment	Accumulated 766 million € by 2020 (accumulated additional cost 524 million € compared to reference scenario)
Operating costs	10.7 million € in 2020
Emission reduction*	Emission reduction is accounted for in the energy sector

* Compared to the reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge B-4

As the relevant energy source is electricity, photovoltaic is allocated to the energy supply and the effects are further considered in Part B, chapter 7 energy supply. In Table 5.35 transformation input and transformation output are compared. As, according to the Austrian Energy Balances, the efficiency factor of photovoltaic is assumed 100 transformation input is equal to transformation output. Increased efficiency of photovoltaic panels, caused by technological improvements is not visualised, but will be expressed by e.g. smaller panels with the same capacity to be installed.

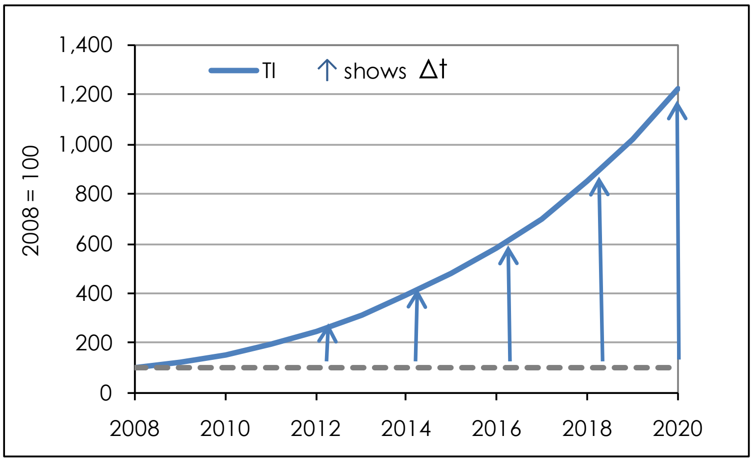
Table 5.35: Technology Wedge B-4: Summary of energy indicators

	2008 2008=100	**2020/2008** %	**2020** 2008=100
Transformation Output (TO)	100	1,124	1,224
Transformation Input (TI)	100	1,124	1,224

Source: Own calculations.

Figure 5.20 demonstrates the development of indices according to the EnergyTransition methodology. The graph illustrates the change of the transformation input of photovoltaics (= transformation output, see above). The blue arrows illustrate the increase of the transformation input up to 1,224% in 2020 compared to 2008.

Figure 5.20: Technology Wedge B-4: Effects on transformation input[1]



Source: Own illustration. – [1] Δt describes the combined effect of changes in transformation output and transformation efficiency. TI is Transformation input.

Assuming that the capacity of the photovoltaic panels will increase more than tenfold from 32 MW_p in 2008 (equivalent to about 0.1 PJ) up to 354 MW_p (ca. 1.3 PJ) by 2020 and assuming the decrease of electricity demand in buildings in the technology wedge scenario will be fully achieved by a substitution of coal and gas power plants (for electricity) 0.2 million t CO_2 could be saved in the wedge scenario compared to the reference scenario, where the capacity is expected to increase only to 130 MW_p. For detailed description of the energy supply wedges see Part B, chapter 7.

Economic Aspects

Current average system costs are about 3,500 €/kW_p. However, it is expected that there is a significant cost decrease until 2020, due to the global market expansion of PV technology. For the economic considerations in this technology wedge, a 5% p.a. cost reduction has been assumed (starting in 2011), in total 50% up to 2020. The total investment volume for additional capacities of photovoltaic energy installed in 2020 has been calculated at about 95 million € (accumulated ca. 766 million € between 2009 and 2020). Compared to a reference path an additional investment volume of ca. 70 million € in 2020 is necessary (accumulated 524 million € between 2009 and 2020). Table 5.36 summarises the investment volume and the operating costs of Technology Wedge B-4. The investment costs include expenditure for the photovoltaic panels and the supplementary installation. Operating costs include maintenance costs of 30 €/MWh and electricity costs of 170 €/MWh. Cost savings are about 50 million € in 2020.

Table 5.36: Technology Wedge B-4: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	25	35	41	49	57	68	63	71	79	88	96	95
Additional Costs	11	19	24	30	38	47	43	49	57	64	72	70
Operating costs	1	1	2	2	3	3	4	5	6	7	9	11
Additional Costs	-5	-6	-8	-10	-13	-16	-20	-24	-29	-35	-42	-50

Source: BMVIT (2007); own calculations.

Table 5.37 and Table 5.38 illustrate the disaggregation of the investment and operating costs. Due to the cost structure the sectors rubber and plastic products, non metallic mineral products, fabricated metal products, electrical machinery, building installation as well as precision instruments are most strongly affected by the investment of the photovoltaic storyline.

Table 5.37: Technology Wedge B-4: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Rubber & plastics products	12	0	12	0
other non metallic products	8	0	8	0
fabricated metal products	10	1	10	1
Electrical machinery	45	1.8	45	1.8
building installation	15	1.2	15	1.2
precision instruments	10	0.4	10	0.4
Total	100	4.4	100	4.4

Source: PVT Austria (2010); own calculations.

The operating costs are split in service and maintenance costs (80%), further in insurance (15%) and other costs (5%).

Table 5.38: Technology Wedge B-4: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Maintenance cost	80	-80
Insurance	15	-15
other costs	5	-5
Total	100	-100

Source: Own calculations.

Cost appraisal

For the calculation of annualised costs of photovoltaics, investment costs of 3,500 €/kWp, a service life of 25 years and an interest rate of 2.5% are used.

The operating costs are taking into account a specific energy production of 900 kWh/kWp (in 2008) that will increase to about 1,000 kWh/kW$_p$ in 2020 and constant electricity costs of 170 €/MWh. The user costs of capital amount to 253 €/MWh.a in 2008 and are expected to fall significantly to 113 €/MWh.a in 2020. Total annualised costs (investment and operating costs) of photovoltaics are 283 €/MWh.a (2008) and 143 €/MWh.a (2020).

Table 5.39: Cost appraisal of photovoltaics

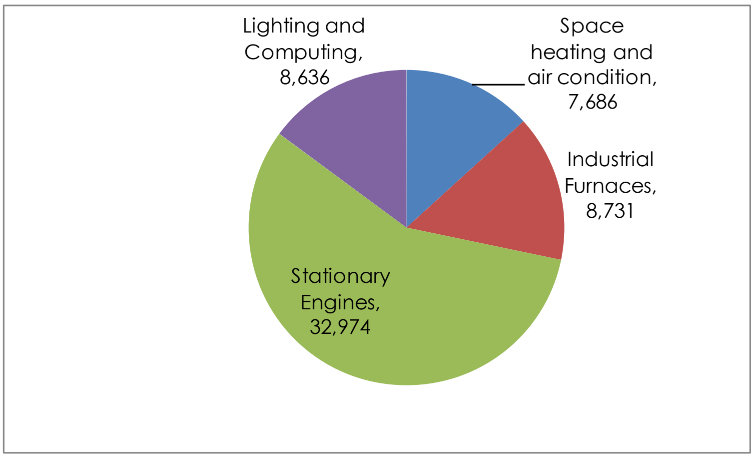
Photovoltaics		Residential & non-residential	
		2008	2020
Investments			
Service life	years	25	25
Interest rate	% p.a.	2.5	2.5
Investment price	€/kWp	3,500.00	1,750.00
User cost of capital	***€/MWh.a***	***252.80***	***112.80***
Operating			
Operating costs	€/MWh.a	30.00	30.00
Total costs	***€/MWh.a***	***282.80***	***142.80***
Reference price for electricity	***€/MWh***	***170.00***	***170.00***

Source: BMVIT (2007); own calculations.

5.3.6 Technology Wedge B-5: Energy optimised appliances, lighting and equipment – continuous exchange of obsolete appliances through new super-energy efficient equipment.

This technology wedge has been identified on the basis of the present electricity demand, the forecasted annual increase of about 1.2% (see also chapter 5.1) and the assumption that the penetration rate of energy optimised appliances will increase continuously and become state-of-the-art. Figure 5.21 demonstrates the electricity demand of the household sector.

Figure 5.21: Electricity demand of households in TJ, 2008



Source: Statistics Austria (2009b).

Main reasons for the continuous increase of the electricity demand of private households of about 1.2% p.a. are:

- demographic development
- the trend towards single person households
- the growing stock of household appliances in general

According to the EU's 20-20-20 objectives a significant contribution for energy savings has to be made by households. As Brauner (2006) shows a possible electricity saving potential of 30% without any comfort losses is realistic:

- exchange of electrical appliances through energy efficient new ones
- reduction and elimination of stand-by-consumption
- further improvement of products (eco-design)
- changed user behaviour

The electricity demand of a four person household with an average of 4,400 kWh/a can be potentially reduced to about 3,080 kWh/a (-30%), resulting also in significant cost savings (average up to 225 €/a, based on current prices). Table 5.40 gives an overview of current energy consumption and potential savings for various categories of appliances.

Table 5.40: Energy savings of typical household appliances

Appliance	Stock	Standard in kWh/a	Optimised	Savings in %
Refrigerator	380	225	100	73.7
Fridge-freezer	550	320	190	65.5
Washing machine	400	250	80	80
Tumble drier	750	650	530	29.3
Dishwasher	390	300	215	44.9
Cooker	620	520	410	33.9
TV, middle-size	300	220	150	50
PC, Monitor	180	110	60	66.7
Lighting	500	300	110	78

Source: topprodukte.at; own calculations.

In Table 5.41 the main assumptions and characteristics of Technology Wedge B-5 'Energy optimised appliances', lighting and equipment are summarised.

Table 5.41: Summary Table for Technology Wedge B-5

Energy optimised appliances, lighting and equipment	
Energy optimised appliances	Continuous exchange of electrical household appliances through energy efficient new ones, reduction and elimination of stand-by-consumption and change of user behaviour
Energy service	The average annual increase in new appliances is rising from about 2.92 million (2008) to 3.29 million (2020), which is +13%. In total, ca. 40 million new appliances are bought during this period.
Technology	Highly efficient household appliances, lighting, communication and consumer electronics can reduce the demand of a typical 4 persons household up to 30% (by 2030) and up to 50% (by 2050).
Required capacity increase*	None
Diffusion path	Linear
Total investment	An estimated 17,273 million € (accumulated) will be invested into new household appliances by 2020 (1,519 million € in 2020). Additional costs for energy efficient appliances compared to standard appliances is negligible.
Operating costs	786 million € in 2020, cost savings of about 527 million € are calculated.
Emission reduction*	Emission reduction accounted for in the energy sector

* Compared to the reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge B-5

Starting from the current stock of electrical appliances and the associated electricity demand savings potentials of energy efficient appliances are calculated. For approximately half of electricity consumption of the household sector (excl. electrical heating, demand for pumping in heating systems)[27], a substitution of standard appliances by energy efficient appliances is assumed. The energy service (S) shows the growth in the number of – new energy efficient – devices from about 2.92 million to 3.29 million between 2008 and 2020. The energy service therefore rises by about 22% until 2020 (compared to 2008). Useful energy intensity (u) will be reduced by about 33% (on average for all appliances) as a result of improved efficiency of the appliances. Table 5.42 shows the energy indicators for Technology Wedge B-5 and the share of the relevant energy source.

Table 5.42: Technology Wedge B-5: Summary of energy indicators

Energy efficient household appliances	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Services			
Energy Service	100	8	108
Energy intensities			
Useful Energy Intensity (u)	100	-33	67
Final Energy Intensity (f)	100	0	100
Final Energy (F)	100	-27	73

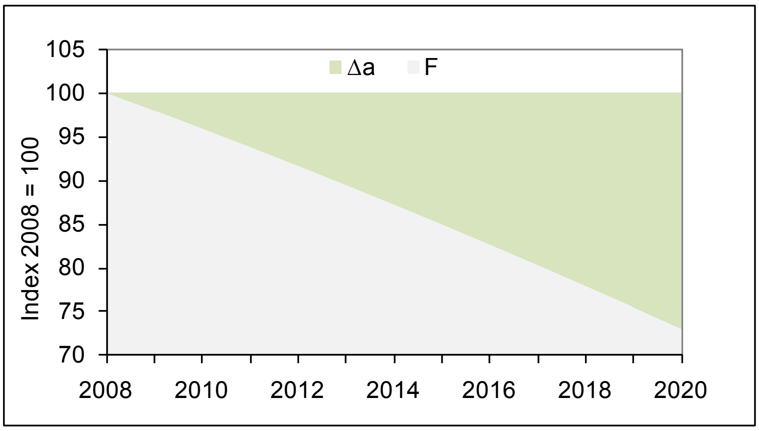
Fuel Shift	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	0.0	0.0	0.0
Gas	0.0	0.0	0.0
Renewables	0.0	0.0	0.0
Electricity	100.0	0.0	100.0
Heat	0.0	0.0	0.0
TOTAL	100.0	0.0	100.0

Source: Statistics Austria (2009b), Forum Hausgeräte (2008); own calculations.

The development of final energy demand following the exchange of inefficient household appliances is shown in Figure 5.22. Final energy demand (F) decreases from 100 (2008) to 73 (2020).

[27] Following Strom- und Gastagebuch 2008, Statistics Austria.

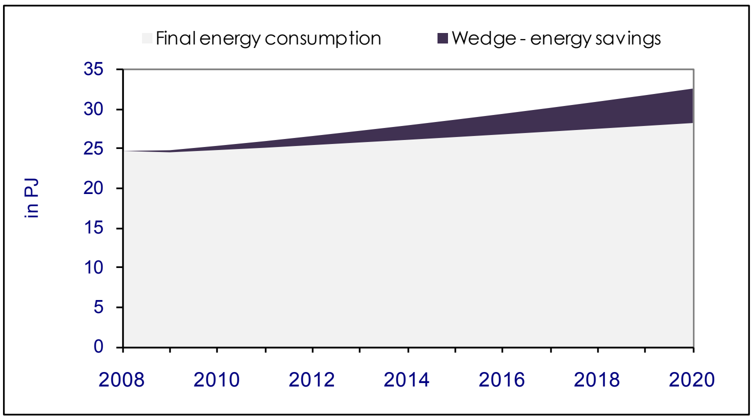
Figure 5.22: Technology Wedge B-5: Development of final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption.

Figure 5.23 shows the absolute change in final energy demand.

Figure 5.23: Technology Wedge B-5: Effects on final energy consumption



Source: Statistics Austria (2009b), Forum Hausgeräte (2008); own calculations.

Assuming that the decrease of electricity demand in buildings in the wedge scenario will be fully achieved by a substitution of coal and gas power plants (for electricity), ca. 0.9 million t CO_2 could be saved, compared to the reference scenario. For detailed description of the energy sector wedges please refer to Part B, chapter 7.

Economic Aspects

The exchange of outdated inefficient household appliances has been estimated with a total volume of 1,519 million € in 2020, which will be invested for new appliances (accumulated 17.3 billion € between 2009 and 2020). Additional costs are negligible, as energy efficient appliances of all kinds can be purchased today more or less at the same costs[28]. Table 5.43 demonstrates the development of investment and operating costs. The investment costs include the costs of the appliances (average equipment costs multiplied by the number of new purchased devices). Operating costs consist of electricity as well as service and maintenance costs. Operating costs are reflecting basically the amount of electricity used by an average 4-person household (incl. all relevant costs for electric equipment spent) multiplied by the number of households and are calculated to be about 1.13 billion € in 2009 and decreasing by about 30% to approx. 786 million € in 2020. By 2020, the savings in operating costs (compared to the reference scenario) are about 527 million €, which will be achieved by a reduced electricity demand and assumed constant electricity prices (170 €/MWh).

Table 5.43: Technology Wedge B-5: Development of investment and operating costs (in million €)

in m €	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	1,362	1,376	1,389	1,403	1,417	1,431	1,446	1,460	1,475	1,490	1,504	1,519
Additional Costs						n.a.						
Operating costs	1,133	1,102	1,070	1,039	1,007	975	944	912	881	849	818	786
Additional Costs	-43	-87	-130	-174	-217	-261	-305	-349	-393	-438	-482	-527

Source: Statistics Austria, Forum Hausgeräte (2008/10), AWEESS (2010); own calculations.– n.a. is not available.

The following Table 5.44 and Table 5.45 illustrate the disaggregation of the investment and operating costs. The sectors rubber and plastic products, fabricated metal products, machinery and equipment, computers as well as Radio, Television and communication equipment are most strongly affected by the investment in efficient household appliances.

Table 5.44: Technology Wedge B-5: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Rubber & plastics products	30	30	30	30
fabricated metal products	30	24	30	24
Machinery & equipment	20	16	20	16
Computers	10	7	10	7
Radio, TV, comm. Equipment	10	10	10	10
Total	100	87	100	87

Source: Statistics Austria; own calculations.

The operating costs are split in especially electricity costs (95%) and maintenance costs.

[28] Source: klima:aktiv „energieeffiziente geräte“: survey of public procurement results in Austria comparing purchase prices of energy efficiency electricity appliances with “regular” ones available on the market.

Table 5.45: Technology Wedge B-5: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel costs	95	-95
Maintenance cost	5	-5
Total	100	-100

Source: Own calculations.

Cost appraisal

For the calculation of annualised costs of new efficient appliances, average investment costs of 462 €/appliance and a service life of 15 years are the basis. Furthermore an interest rate of 2.5% is used for the calculations.

The operating costs are based on an electricity demand for efficient appliances (1,920 kWh per household and constant electricity costs of 170 €/MWh). The user costs of capital amount to 18 €/MWh.a in 2008 and 27.8 €/MWh.a in 2020. The total costs (annualised investment and operating costs) of efficient appliances are 31.2 €/MWh.a in 2008 and 39.9 €/MWh.a in 2020. Higher total costs result from the increasing number of household appliances until 2020.

Table 5.46: Cost appraisal of new efficient appliances

Energy optimised appliances		**Residential & non-residential**	
		2008	**2020**
Investments			
Service life	years	15	15
Interest rate	% p.a.	2.5	2.5
Investment price	€/household.a	377.78	392.71
User cost of capital	***€/MWh.a***	***18.04***	***27.79***
Operating			
Operatin costs	€/MWh.a	13.12	12.10
Total costs	***€/MWh.a***	***31.16***	***39.89***
Reference price for	***€/MWh***	***170.00***	***170.00***

Source: Strom- und Gastagebuch 2008, Statistik Austria; Forum Hausgeräte (2008/10), own calculations

5.3.7 Combination of Technology Wedges

The overall emission reduction potential of the building sector is determined by a combination of different technology wedges. Each wedge represents the possibility to contribute to a less energy and carbon intensive building sector. Combining the wedges, it is considered that potential savings are partly overlapping.

The biggest energy savings result from the refurbishment of buildings (B-1) and high efficient new buildings (B-2). These two wedges are completely additional and can achieve a saving of about 42.07 PJ (compared to a reference scenario). Technology Wedge B-5 relating to the diffusion of energy efficient appliances can also be accounted for fully. Its contribution is an energy saving of 6.6 PJ compared to the reference scenario.

Technology Wedge B-3a heating system refers to the significant potential that lies in increasing the efficiency of heating systems (exchange of heating systems and components) as well as a switch to renewable energy systems. This measure is proposed in combination with Technology Wedge B-1 – preferably an exchange of heating systems should go hand in hand with building refurbishment. In this case the energy saving is calculated to be approx. 12 PJ (instead of 16 PJ for an isolated view of the wedge) or 1.47 million t CO_2. The argument is that in the case of a building refurbishment and a subsequent exchange of heating systems the energy saving will be factually less. Similar to the argumentation for Technology Wedge B-3a runs the argument for Technology Wedge B-3b for an intensification of solar thermal energy for heating and hot water preparation. Taking into account the overlapping potential with the energy saving resulting from building renovation, the total effect is estimated to be about 2.5 PJ and CO_2 emissions to decrease by about 0.24 million t.

Effects from Technology Wedge B-4 on photovoltaic electricity production are accounted for in the sector electricity and heat.

In total, final energy demand of the combined wedges of the building sector is reduced by about 60 PJ. This translates into a decrease of CO_2 emissions of about 3.2 million t in 2020 (compared to the reference scenario).

Table 5.47: Changes in final energy demand for wedge combination in 2020 compared to reference scenario

Technology Wedge		Final energy consumption 2020 Difference to Reference in PJ						
		Coal	Oil	Gas	Renewables	Electricity	Heat	Total
B-1	Renovation	-0.51	-9.18	-7.49	-9.72	-2.12	-6.20	-35.22
B-2	New building	0.00	-2.26	-1.91	-2.06	0.86	-1.4754	-6.85
B-3a	Replacement heating	-1.30	-12.35	-6.94	7.66	-3.25	4.71	-11.48
B-3b	Solar heating	-0.17	-1.74	-1.56	2.67	-0.15	-1.52	-2.48
B-4	Photovoltaics			not applicable				
B-5	Efficient appliances					-6.63		-6.63
	Total	-1.99	-25.54	-17.90	-1.46	-11.29	-4.48	-62.66

Source: Statistics Austria (2009a, b); own calculations.

Table 5.48: Changes in CO_2 emissions for wedge combination in 2020 compared to reference scenario

Technology Wedge		CO_2 emissions 2020 Difference to Reference in million t						
		Coal	Oil	Gas	Renewables	Electricity	Heat	Total
B-1	Renov ation	-0.05	-0.72	-0.41	0.00	0.00	0.00	-1.18
B-2	New building	0.00	-0.18	-0.11	0.00	0.00	0.00	-0.28
B-3a	Replacement heating	-0.13	-0.96	-0.38	0.00	0.00	0.00	-1.47
B-3b	Solar heating	-0.02	-0.14	-0.09	0.00	0.00	0.00	-0.24
B-4	Photov oltaics	not applicable						
B-5	Efficient appliances	not applicable						
	Total	-0.19	-1.99	-0.98	0.00	0.00	0.00	-3.17

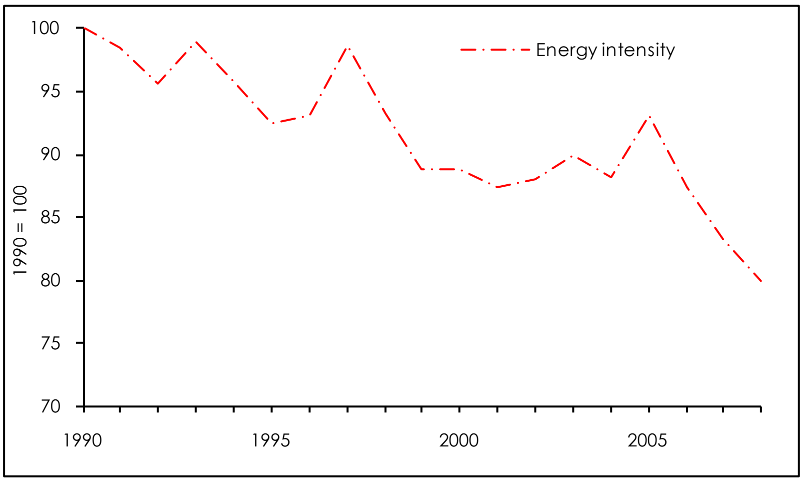
Source: Statistics Austria (2009a, b); own calculations.

6 Energy services and implementing the concept of technology wedges for Workpackage 3 – Industry

6.1 Introduction

Industry's share in final energy consumption increased in the last decade of the past century despite rising energy efficiency (Figure 6.1).

Figure 6.1: Energy intensity of the manufacturing industry 1990-2008



Source: Statistics Austria (2009a). – Final energy consumption in TJ per gross value added at constant prices in million €.

For Austrian manufacturing energy services for different production processes are analysed within the project EnergyTransition. Industry sectors are disaggregated according to energy intensity in different production sectors. According to a systematic approach, energy services can be structured similar to unit operations common in process engineering. Unit operations are basic steps in a process. For example in food processing, homogenisation, pasteurisation, chilling and packaging are each unit operations which can be combined in the overall production process.

Typically different industry sectors are viewed as different industrial processes with different production concepts. But in general, there are only four different kinds of unit operations:

- Thermal Unit Operations – drying, distillation, extraction, absorption, adsorption,
- Mechanical Unit Operations – sifting, filtering, sediment, air-floating, centrifugation,
- Chemical Unit Operations – chemical reactors, absorption, extraction according to chemical reactions, permeation and
- Support Unit Operations – heat-exchange, blending, homogenisation, milling, dispersing.

Disaggregation into unit operations is useful – for empirical analysis the level of detail has to be constrained to a manageable complexity. Therefore selected energy services within the project EnergyTransition are classified based on the Austrian Energy Statistics (Statistics Austria, 2009a, b; see Part B, chapter 1). With respect to unit operations and useful energy categories, the following energy services are defined.

Thermal energy services

In the analysis of the production sector thermal energy services are separated into three different temperature levels. The first temperature array is below 100°C, the second is between 100°C and 400°C and the third is above 400°C. Based on the Austrian Useful Energy Balances (Statistics Austria, 2009b) thermal energy services can be found in the following categories:

- Space heating
  - includes heating of production halls and related buildings
  - usually provided on a temperature level under 100°C
- Steam production
  - includes the supply of steam from boilers
  - usually provided on a temperature level between 100°C and 250°C
- Industrial furnaces
  - includes the supply with energy on high temperature level
  - usually provided on a temperature level from 100°C to more than 400°C
- Drying
  - includes all drying processes
  - usually provided on a temperature level under 100°C
- Warm water
  - includes the supply with warm water
  - usually provided on a temperature level under 100°C

Mechanical energy services

Mechanical energy services cover the provision of mechanical and kinetic energy. They are provided by engines which transform thermal, chemical or electrical energy into mechanical or kinetic energy. Generally production sectors have a considerable and increasing share of this service because of rising automation of technical processes. Mechanical energy services in this analysis are mainly produced by stationary engines.

According to the Austrian balances of useful energy the following useful energy categories correspond to the mechanical energy services:

- Stationary engines
- Traction

Specific electrical energy services

Specific electrical energy services can only be provided by the utilisation of electricity. Energy services are provided by transforming electricity into other forms of energy like radiation (lighting). In this context, electricity is mainly used for illumination and electronics. The overall amount for this service shows no significant increase in the last years.

The following useful energy category accrues to the specific electrical energy services:

- Lighting and computing

Electrochemical energy services

Electrochemical energy services refer to electricity as part of a chemical reaction. Without this energy input the reaction would either not happen or in an uneconomic span of time. In some cases it just provides the reaction power, but in other ones it is also the reacting agent. Some examples for this service are the electrical production of steel or electrolysis as a part of the aluminium production. The useful energy category 'Electro-chemical purposes' corresponds to the electrochemical energy services.

6.1.1 Facts, Data and Status Quo

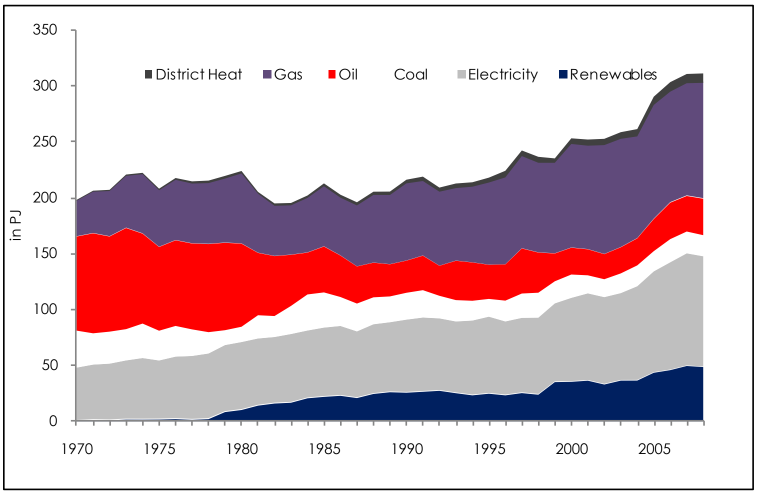
The structural change of the Austrian economy and the increase in energy efficiency in production processes resulted in a decrease of energy intensity[29] of the manufacturing industry of 20% between 1990 and 2008. Overall Austrian energy intensity fell by 6% over the same period. Along with economic growth energy demand in the manufacturing sector rose between 1990 and 2008 by 44% compared to total energy demand which showed an increase of 42%.

Austrian Energy Balances

Final energy demand is constantly rising. In 2008 the share of the production sector in total Austrian final energy consumption was 29%. The largest part accrues with 103,693 TJ to gas consumption. A slightly lower amount (98,685 TJ) of electricity is used in manufacturing. In the last years, there was a considerable transition from emission intensive fossil fuels to energy sources with lower emission intensity. Furthermore, the contribution of renewables is steadily increasing (Figure 6.2).

[29] Final energy consumption in TJ per gross value added at constant prices in million Euro.

Figure 6.2: Final energy consumption in the production sector by energy source



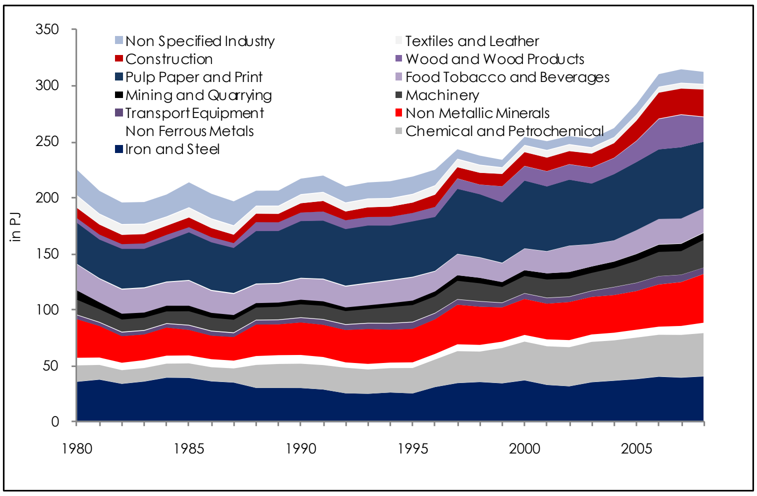
Source: Statistics Austria (2009a).

In the Austrian Energy Balances (Statistics Austria, 2009a) the production sector is differentiated by the following sub-sectors:

- Iron and Steel
- Chemical and Petrochemical
- Non-ferrous Metals
- Non-metallic Minerals
- Transport Equipment
- Machinery
- Mining and Quarrying
- Food, Tobacco and Beverages
- Pulp, Paper and Print
- Wood and Wood Products
- Construction
- Textiles and Leather
- Non Specified (Industry)

The current large share of energy intensive industry sectors results from a traditionally strong focus on basic industries within the Austrian industry structure. With respect to energy demand, since 1980 only a few sectors show an above-average growth rate. In this context two production sectors should be specially highlighted: The chemical industry, which shows a 150% increase in the demand for energy compared to 1980, and pulp and paper production with an increase of 75% (Figure 6.3).

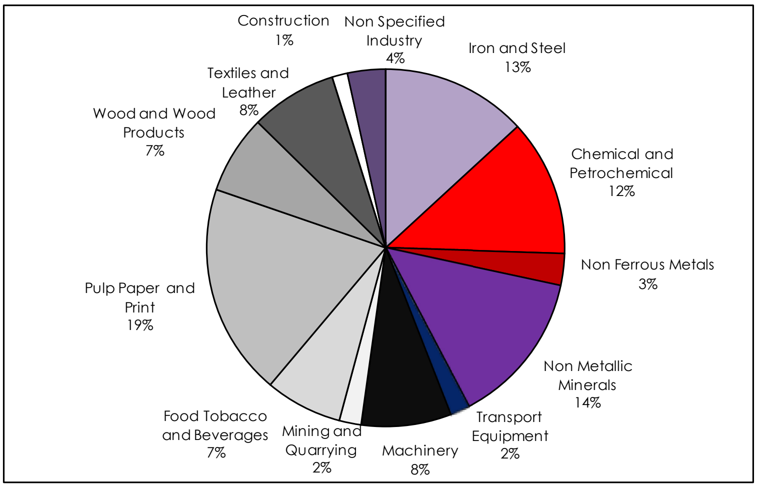
Figure 6.3: Final energy consumption by industry sector



Source: Statistics Austria (2009a).

Figure 6.4 illustrates final energy demand disaggregated by production sectors in 2008.

Figure 6.4: Final energy consumption by industry sector in 2008



Source: Statistics Austria (2009a).

The five production sectors with the highest energy demand are discussed in the following chapters. They are ranked by their total energy consumption in the year 2008 (Table 6.1).

Table 6.1: Top 5 production sectors by energy demand

	1990	1995	2000	2008
		TJ		
Pulp, Paper and Print	51,194	49,979	60,926	59,713
Non Metallic Mineral	22,008	23,024	34,532	43,384
Iron and Steel	30,628	25,828	37,514	41,016
Chemical and Petrochemical	29,103	30,036	32,109	38,508
Machinery	12,245	15,525	16,014	25,366
Total	216,571	218,416	253,786	311,835

Source: Statistics Austria (2009a).

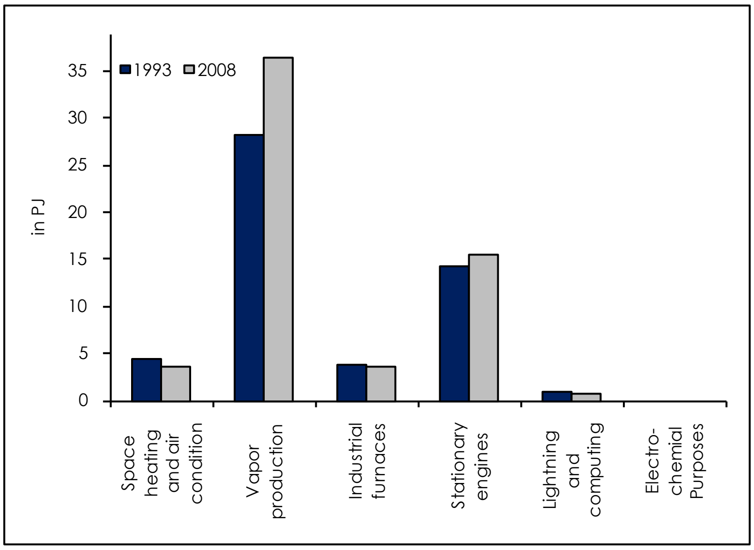
Paper and Pulp

The front-runner with respect to energy consumption in 2008 was paper and pulp production which includes:

- Manufacture of pulp, paper and paperboard
- Manufacture of articles of paper and paperboard
- Publishing
- Printing and service activities related to printing
- Reproduction of recorded media

This industry sector accounted for 20% of final energy demand of the whole manufacturing industry. Figure 6.5 shows into which useful energy categories it was transformed. Over 70% are used for thermal energy services and nearly 25% are needed for the category stationary engines. There were no relevant changes as to the shares of these categories in the last 15 years (Figure 6.5). In 2008 43,471 TJ of thermal energy were used in the paper and pulp sector, only 17% of this energy amount were on a temperature level over 400°C. Most of the energy is required on a level from 100°C to 400°C. The temperature distribution was calculated according to the structure of the EU-25 manufacturing industry.

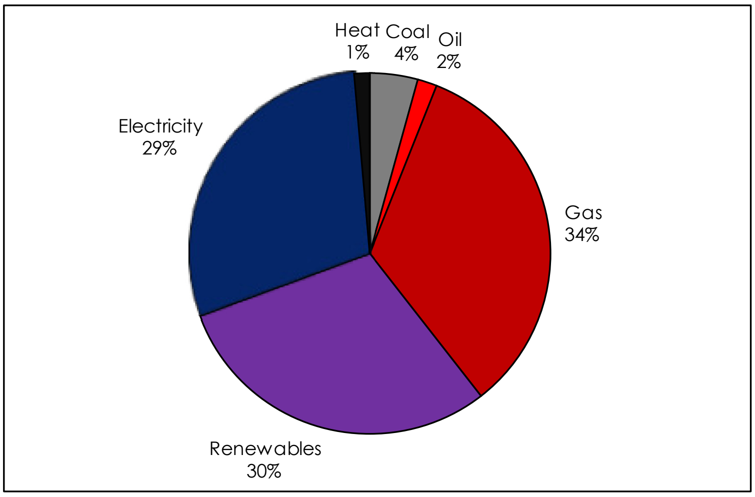
Figure 6.5: Final energy consumption by use category, 1993 and 2008



Source: Statistics Austria (2009b).

Figure 6.6 shows final energy consumption by energy source. Nearly one third of energy demand was each supplied by gas, electricity and renewable sources. The strong contribution of renewable energy is due to the combustion of organic waste from the production process. Thermal energy demand is constant over the whole year; hence combined heat and power plants are already used in a number of production sites.

Figure 6.6: Final energy consumption of the sector Pulp, Paper and print by energy source, 2008



Source: Statistics Austria (2009a).

Iron and Steel

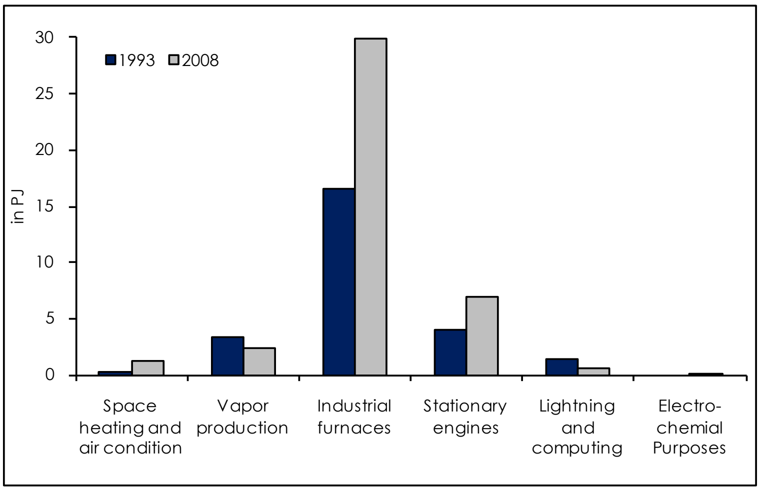
Iron and steel production is on second rank in energy demand of manufacturing. Production activities in this sector are:

- Manufacture of basic iron and steel and o ferro-alloys
- Manufacture of tubes, pipes, hollow profiles and related fittings
- Other first processing of iron and steel
- Manufacture of basic precious and non-ferrous metals
- Casting of metals

82% of energy demand in this sector is used for thermal energy services. Most of the heat is produced by industrial furnaces on a temperature level over 400°C (93% of thermal energy). Compared to total demand of 41,016 TJ only a small amount, about 18 TJ, is used for electrochemical purposes.

In the iron and steel sector the energy using systems are up to 40 years old. Because of these age patterns there were no relevant changes in the distribution of useful energy categories during the considered period (Figure 6.7). For a switch to one of the new relevant techniques, which were explored in the last decades, it will be necessary to build new blast furnaces.

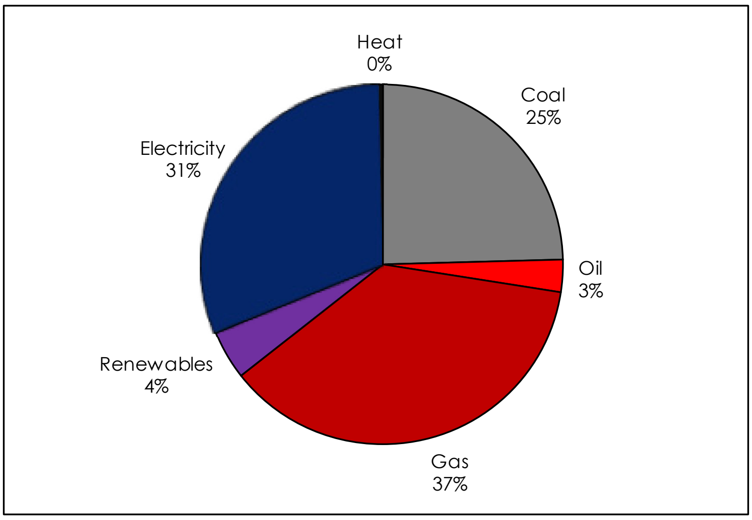
Figure 6.7: Final energy consumption of iron and steel production by use category, 1993 and 2008



Source: Statistics Austria (2009b).

Over 25% of total energy demand is covered by coal; the rest is based on fossil energy sources and electricity. Only 1,809 TJ are contributed by renewable sources (Figure 6.8).

Figure 6.8: Final energy consumption of iron and steel production by energy source, 2008



Source: Statistics Austria (2009a).

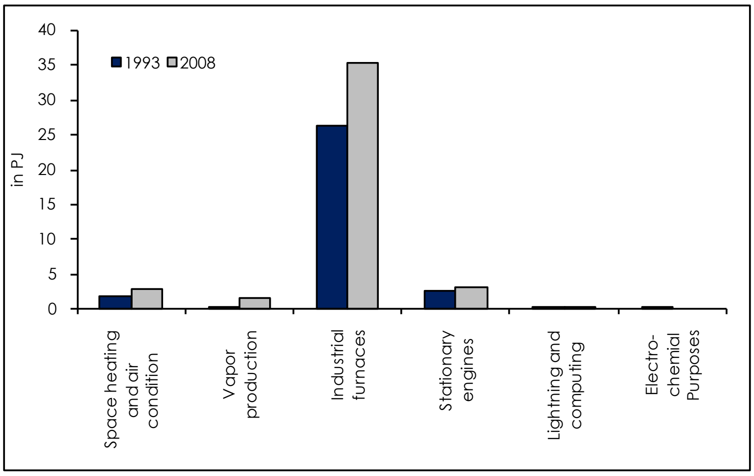
Non Metallic Minerals

With a final energy demand of 43,384 TJ in the year 2008, the non-mineral sector has the third highest final energy consumption. The following production activities are included:

- Manufacture of glass and glass products
- Manufacture of non-refractory ceramic goods other than for construction purposes; manufacture of refractory ceramic products
- Manufacture of other porcelain and ceramic products
- Manufacture of cement, lime and plaster
- Manufacture of articles of concrete, plaster and cement
- Cutting, shaping and finishing of ornamental and building stone
- Manufacture of other non-metallic mineral products

Based on the manufactured products and the associated processes 81% of the energy services belong to the useful energy categories industrial furnaces. Nearly 90% of thermal energy services are supplied on a temperature level over 400°C (Figure 6.10). Compared to the other useful energy categories stationary engines show a slight increment in the last 15 years. Nearly 22% of the energy is provided by renewable energy sources. This rather high share is caused by the combustion of organic fuel surrogate for thermal energy services (Figure 6.10).

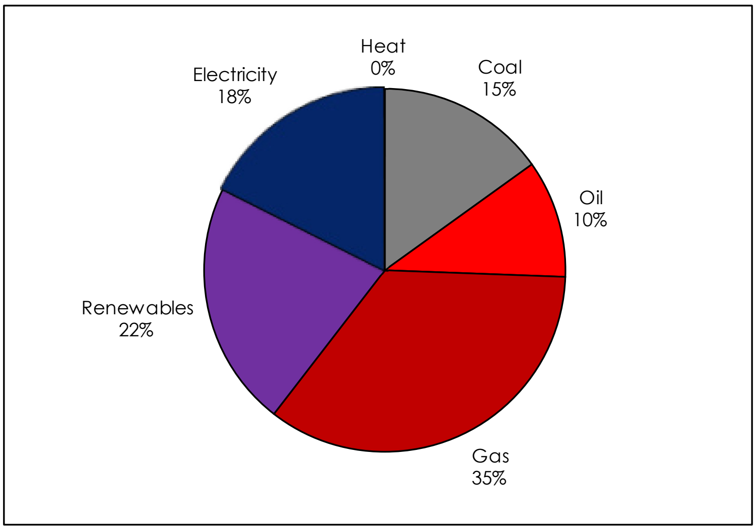
Figure 6.9: Final energy consumption of non metallic mineral production by use category, 1993 and 2008



Source: Statistics Austria (2009b).

Except for the recycling of waste, energy consumption of this sector is mainly based on fossil fuels. Since the implementation of the European emissions trading scheme there was a considerable transition from emission intensive fossil fuels to natural gas.

Figure 6.10: Final energy consumption of the sector non metallic minerals by energy source, 2008



Source: Statistics Austria (2009a).

Chemical and Petrochemical

Final energy consumption in the chemical and petrochemical industry was 38,508 TJ in 2008. The NACE definition of this sector includes the following activities:

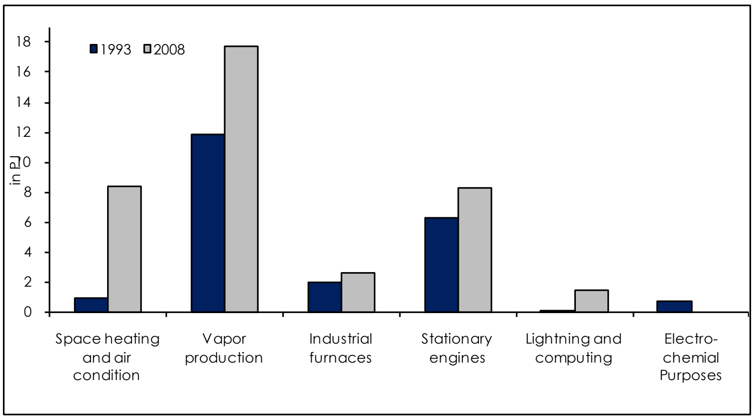
- Manufacture of basic chemicals

- Manufacture of pesticides and other agro-chemical products
- Manufacture of paints, varnishes and similar coatings, printing ink and mastics
- Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
- Manufacture of other chemical products
- Manufacture of man-made fibres

From 1993 to 2008 energy demand in this sector nearly doubled. 62% are used for steam production and altogether 75% of the energy services are thermal. One quarter is needed on a temperature level below 100°C and a half in the range over 400°C.

In 2008 in the useful energy category space heating and air-conditioning absolute energy consumption was 10 times higher than in 1993 (Figure 6.11).

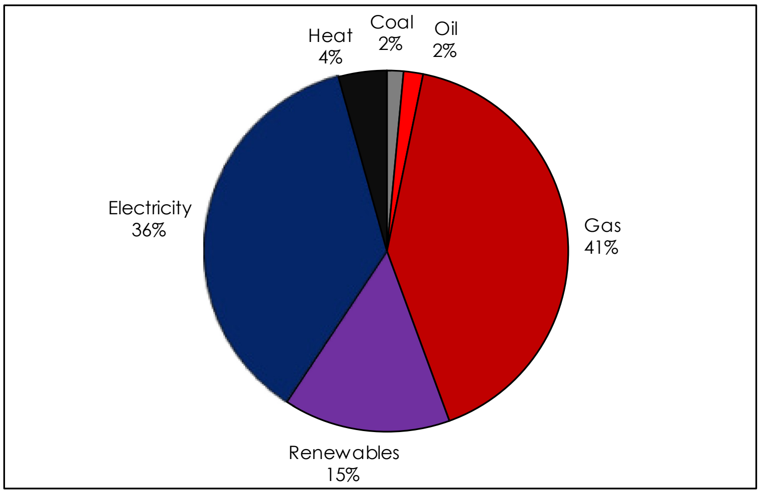
Figure 6.11: Final energy consumption of the sector chemical and petrochemical by use category, 1993 and 2008



Source: Statistics Austria (2009b).

Again in this sector, there was a noticeable switch to lower-emissions fuels like natural gas. In the last years the contribution of renewable sources grew up to 15%. Like in all other sectors electricity demand is rising constantly.

Figure 6.12: Final energy consumption of the sector chemical and petrochemical by energy source, 2008



Source: Statistics Austria (2009a).

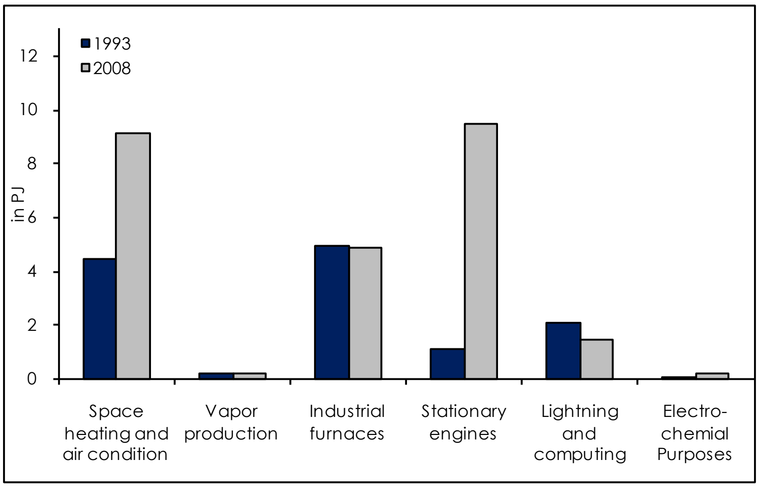
Machinery

The last sector discussed is manufacturing of machinery, with a total energy demand of 25,366 TJ in 2008. This sector comprises:

- Manufacture of machinery general purpose machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines
- Manufacture of other general purpose machinery
- Manufacture of agricultural and forestry machinery
- Manufacture of machine tools
- Manufacture of other special purpose machinery

Over 70% of energy demand are needed in two categories, space heating and stationary engines. According to the production processes in the machinery sector, 67% of the heat demand is on a level under 100°C. Figure 6.13 presents the contribution of the useful energy categories in 1993 and in 2008. There are only above average increments in the two categories.

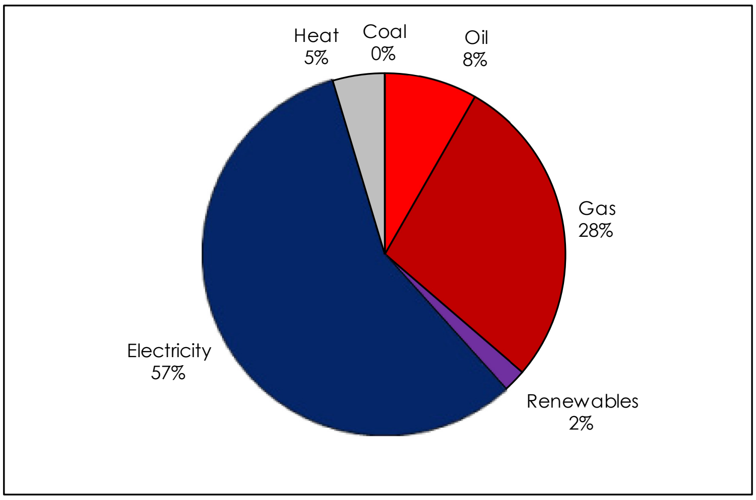
Figure 6.13: Final energy consumption of the sector machinery by use category, 1993 and 2008



Source: Statistics Austria (2009b).

Due to the high contribution of stationary engines, electricity demand contributes nearly 60% to final energy demand. Figure 6.14 shows the distribution of final energy demand by sources in the year 2008.

Figure 6.14: Final energy consumption of the sector machinery by energy source, 2008



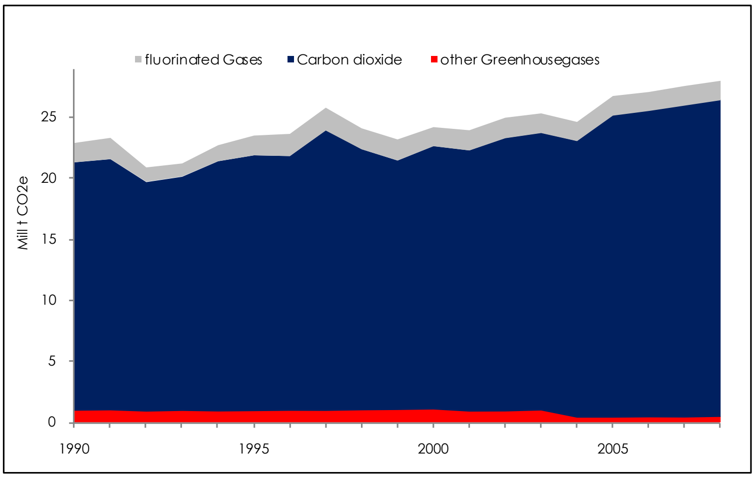
Source: Statistics Austria (2009a).

Austrian Emission Inventory

The Austrian Emission Inventory is based on the Austrian Energy Balances and additional information. The Austrian Emission Inventory is published under survey of UNECE; therefore the applied emission factors and calculation methods are in line with international standards.

The emissions trends in manufacturing are shown in Figure 6.15. Because of the increasing switch to low-emission energy sources, total emissions grew slower than energy demand. Since 1990 there were no significant increments of other greenhouse gas emissions. Under the UNECE directives all of the Austrian fluorinated gases are allocated to the production sector.

Figure 6.15: Emissions of the Austrian production sector from 1990 to 2008 by greenhouse gas



Source: UBA (2010).

6.1.2 *Challenges and relevant technology developments*

The focus on energy services for the manufacturing sector is important but difficult. Availability and profitability hamper the diffusion of new technologies as investors often act risk-avers. As long as energy costs are not a major cost factor in production energy savings will not motivate the use of new technologies. Nevertheless, some new energy saving technological approaches can be identified:

Efficiency

- high level of efficiency throughout all transforming processes

Effectiveness

- intensive specific energy services related to the benefit

Substitution

- replacement of scarce, expensive and non-sustainable energy sources and structures by means of abundant and renewable ones

For all three options new technologies are necessary. The special challenges of innovation are the specific internal energy structures (heat integration, cogeneration of electricity/heat/cooling), which often can be solved specifically without the requirement of new technological solutions. Further technological developments are essential for process intensification. However, further research and development in this area is necessary.

Currently final energy consumption of the production sector is based on fossil energy sources. Only in a few sectors renewable energy sources play a relevant role. Despite the simultaneous consumption of electricity and heat, cogeneration is little used compared to the technical advantages. Other applications of renewable sources are currently rarely used; there are only a few solar thermal plants for cleaning, drying or heating applications.

Incentives to increase energy efficiency not only in production but also in consumer goods are limited at the moment and need to be increased in order to reduce energy demand during the use phase of products supplied by manufacturing.

6.1.3 Technology wedges for manufacturing

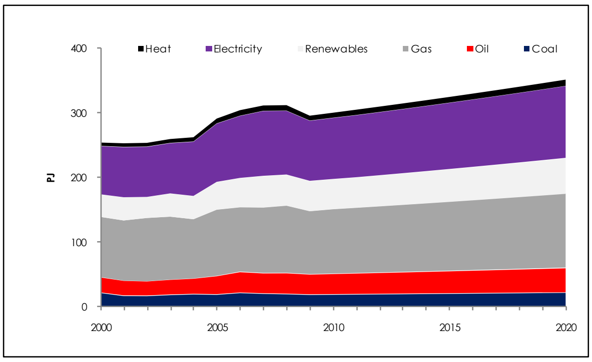
For achieving low carbon production structures, an increase in energy efficiency and hence significant changes in the use of resources are inevitable. The main goal should not only be a reduction of fossil fuels but rather a decrease of energy demand overall.

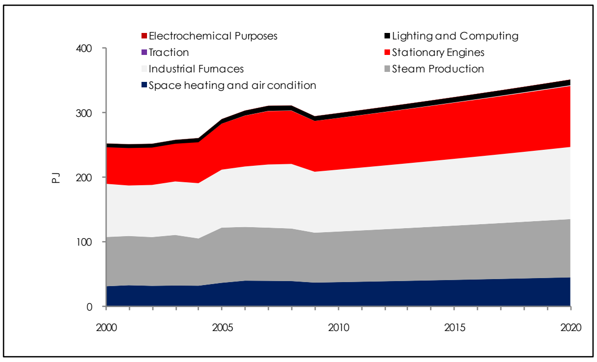
Options for achieving low carbon production structures can be grouped into two categories. In the first category energy demand is reduced; technology wedges in this category can hence be regarded as "efficiency wedges". The second category comprises "substitution wedges" which address a switch from fossil energy sources like coal or oil to low carbon or carbon neutral fuels.[30]

In Part B, chapter 2 the extended technology wedge concept for Austria according to the EnergyTransition methodology is described. The energy and emissions reduction potential is always based on a possible pathway for the development of the energy demand in the reference scenario. The reference scenario for energy and CO_2 emissions in the manufacturing sector serves as a starting point for developing technology wedges for this sector. The methodology and the general results for the reference scenario are described in Part B, chapter 2 and for the manufacturing sector shown in Figure 6.16: On the left side the assumed development of energy demand by energy source is depicted; on the right side projected energy demand by useful energy category is shown.

[30] The technology wedge "combined heat and power" does, however, not fit into this categorisation as it deals with energy supply instead of final energy demand (see section Technology Wedge P-4: Combined Heat and Power).

Figure 6.16: Final energy consumption in manufacturing by energy source (left) and useful energy category (right) – reference scenario





Source: Statistics Austria (2009a, b); own calculations.

The reference scenario can be seen as one possible development path until 2020. Within the two wedge categories seven different technology wedges have been developed, based on a status quo analysis. Based on their technical potential the following technology wedges are analysed with a time horizon until 2020:

- Reducing energy demand of production halls
- Increasing internal efficiency of processes through process intensification and the internal use of waste heat
- Electricity savings through efficient motors and drives and new lighting systems
- Installation of gas driven combined heat and power systems instead of gas fuelled burners
- Substitution of oil or coal fired boilers by gas fired systems
- Use of biomass for the production of thermal energy instead of systems fuelled by fossil sources
- Installation of solar thermal collectors to substitute thermal energy produced by natural gas

The structure of this chapter is as follows: First, the technology wedges for the manufacturing sector are described, based on a detailed storyline discussing the core assumptions that determine emission reductions. Then concrete figures such as technological parameters and cost parameters are given.

Economic data for investment and operating phase

There are some input parameters for the economic data, which are relevant for all wedges. Hence they are described in general for all the wedges.

Economic data are provided for the investment and the operating phase. For both cost categories a differentiation between "total" and "additional" costs is made. For technology wedges for the manufacturing sector "additional costs" are defined as costs that are additional to the costs of a replacement of the machinery. This approach influences the two wedge categories in a different way. Costs of an efficiency wedge are not compared with the costs of a reference technology, because the action is taken, without consideration of a replacement; therefore all the costs or savings are additional.

For substitution wedges the additional costs are calculated according to equation (6.1):

$$(6.1) \qquad costs_{additional} = \sum costs_{Wedge} - \sum costs_{Reference}$$

This calculation method applies both to investment and operating costs. In this context the $costs_{Wedge}$ are the total investment or operating costs of a technology wedge and the $costs_{Reference}$ are the costs (investment or operation) of providing the same energy service with a reference technology. This approach is taken because all substitution measures occur just during the serial replacement of the machinery.

Investment costs

Investment costs are calculated using 2009 prices and assuming constant prices until 2020. Based on data for one plant of an average capacity costs are then estimated for the potential of the whole wedge.

The following assumptions are made:

- continuous annual load hours over the total time period
- no changes in efficiency factors over time
- all costs are average costs
- specific investment costs

Investment costs for two similar plants are seldom identical, because they depend on e.g. existing infrastructure like a connection to the grid. Therefore the costs could differ up to 100% in this respect for two comparable plants. Based on these pre-conditions the average costs from different internal case studies were used for the calculations.

Operating costs

Operating costs are split into fuel costs, maintenance costs and other operating costs. For most technology wedges fuel costs account for the highest share in operating costs and meet the following conditions:

- each technology wedge generates operating costs from the first year of investment until the last year of operation
- none of the technologies for which operating costs are reported have a shorter life span than 10 years

Fuel costs used in the cost analysis are shown in Table 6.2.

Table 6.2: Fuel costs by energy source

Energy Source	fuel costs in €/TJ	References
Hard Coal *Industry*	5,792	Energieträger Jahresdurch-schnittspreise (Statistik Austra, 2010)
Oil *mix of the manufacturing sector*	31,237	AWEEMS (Energieinstitut Linz, 2010)
Natural Gas	18,056	AWEEMS (Energieinstitut Linz, 2010)
Heat	22,500	AWEEMS (Energieinstitut Linz, 2010)
Renewables *Wood chips for energetic utilisation*	5,189	Internationaler Holzmarktbericht (LK-Kärnten)
Electricity *average manufacturing sector*	35,417	AWEEMS (Energieinstitut Linz, 2010)

For efficiency wedges all operating costs are additional costs, because for these wedges no comparison with a reference technology is carried out (see above).

6.2 Storylines for technology wedges for the manufacturing sector

6.2.1 Technology Wedge P-1: Energy demand of industrial buildings

The technology wedge "energy demand of industrial buildings" reduces the energy demand by increasing the thermal efficiency of industrial buildings. Table 6.3 presents the key parameters of Technology Wedge P-1.

Table 6.3: Summary Table for Technology Wedge P-1

Energy demand of industrial buildings	
Reduction of energy demand	7,776 TJ of energy will be reduced in 2020*
Energy service	Production output increases by 23% by 2020
Technology	Reduction of the energy demand of production buildings
Diffusion path	Linear
Total investment	1,577 million € by 2020
Additional operating costs	-171million € in 2020
Emission reduction*	0.247 million t CO_2 in 2020

* Compared to reference scenario.

In the last years growing attention was given to energy savings potentials of industrial buildings. Energy demand for space heating and air conditioning contributed nearly 13% to sectoral final energy demand in 2008. 56% of the energy used for indoor temperature of buildings is provided by fossil fuels.

Many industrial buildings were built in a thermally inefficient way. Therefore their thermal performance is quite poor. In the past these buildings were often heated by the heat losses of the installed engines, but a constant increase of efficiency and a change of technologies lead to a substantial reduction of indoor heat sources. Due to the poor insulation standard of the production halls the external heat or cooling demand rises constantly with the decrease of the thermal losses of the installed engines.

Implementation of EnergyTransition methodology for Technology Wedge P-1

The energy savings potential considered in this technology wedge is based on two measures: The main part is to improve the insulation of the buildings. Data for the specific heat demand used for the calculations are published in the "Design Guidelines – Solar Space Heating of Factory Buildings" (Jähnig, 2007). An average specific reduction of the heat demand by 57 kWh/m²a and an annual refurbishment rate of 1% of the production hall area are the main input parameters for the calculations.

The second part for which a reduction potential was calculated is lighting. Technical solutions, like intelligent illumination systems and the use of daylight, accomplish notable savings in electricity demand for lighting. The potential is calculated based on the numbers of the AWWEEMS study (Energieinstitut Linz, 2010).

Table 6.4 shows the development of the energy indicators according to the EnergyTransition methodology as described in Part B, chapter 3. One has to keep in mind that efficiency measures will lead to overall energy savings and thus also to lower demand of renewable energy. The Table shows the development compared to the total energy demand of the manufacturing sector, therefore the savings in this technology wedge seem to be of marginal size. The changes in fuel mix are the consequences of the energy savings in space heating. This fuel shift in the technology wedge that results from changes in the heating systems of the buildings is also shown in Table 6.4.

Table 6.4: Technology Wedge P-1: Summary of energy indicators

Energy demand of industrial buildings	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	-11	89
Final Energy Intensity (f)	100	0	100
Final Energy (F)	100	10	110

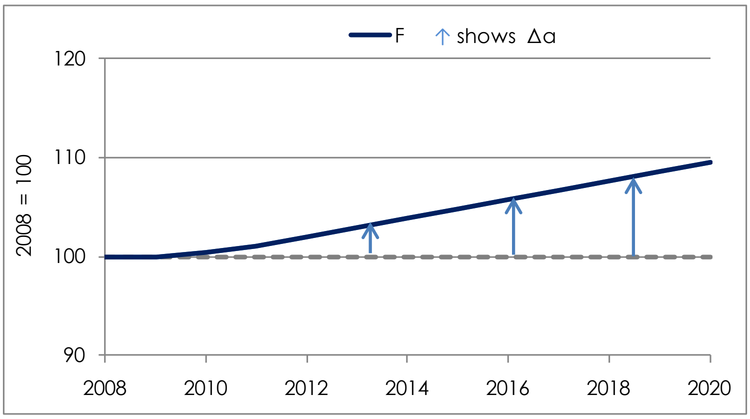
Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	0.0	0.0	0.0
Oil	89.5	-1.4	88.1
Gas	2.8	0.5	3.3
Renewables	4.5	0.9	5.4
Electricity	3.2	0.0	3.1
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

Source: Own calculations.

For the manufacturing sector, the energy service is approximated by output, which is assumed to rise until 2020. The useful energy intensity decreases because of the lower specific energy demand caused by the refurbishment of the production buildings. There are no changes in final energy intensity, because the savings are only induced by the lower specific heat demand of the buildings.

Figure 6.17 shows the development of final energy demand resulting from changes in the energy service and useful energy intensity based on the EnergyTransition methodology, see Part B, chapter 3. Due to the increases in the energy service – approximated by economic output – useful energy demand increases in this wedge. As useful energy intensity is decreasing because of the better insulation of the buildings the increase in energy demand, however, is diminished. This combined effect of the change in the energy service and useful energy intensity (Δa) is illustrated by the light blue arrows in Figure 6.17. The dark blue line shows the resulting development of final energy demand.

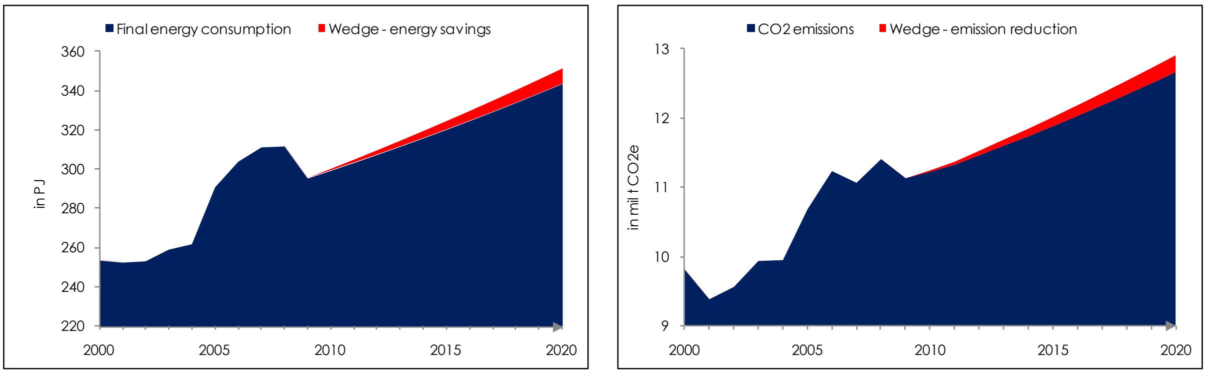
Figure 6.17: Technology Wedge P-1: Effects on final energy demand[1]



Source: Own illustration. - [1] Δa describes the combined effect of changes in energy services and useful energy intensity. F is final energy consumption.

The reduction of final energy demand in this technology wedge can also be compared to the EnergyTransition reference scenario. Figure 6.18 presents the energy and emission reduction potential compared to the EnergyTransition reference scenario. 7,776 TJ of final energy can be saved in 2020, of which the main part belongs to the sources electricity and gas, see also Table 6.5. This reduction in final energy demand is connected with a reduction in CO_2 emissions of 0.3 million t in 2020 compared to the reference scenario.

Figure 6.18: Technology Wedge P-1: Effects on final energy demand (left) and CO_2 emissions (right)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 6.5 presents the results of Technology Wedge P-1: the reduction of oil, gas, heat and a part of the electricity is caused by savings in space heating. This reduction comes from improving the thermal efficiency of the production halls. The remaining reduction in electricity demand is based on higher efficiency of the lighting systems. The decrease in energy demand translates into respective CO_2 emission reductions.

Table 6.5: Technology Wedge P-1: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	22.29	-0.01	0.0	1.99	2.22	0.00	0.0
Oil	32.64	37.05	-1.39	-3.8	2.41	2.74	-0.11	-4.0
Gas	103.69	111.76	-2.49	-2.2	5.70	6.15	-0.14	-2.2
Renewables	48.36	55.06	-0.51	-0.9	1.29	1.53	0.00	0.0
Electricity	98.69	109.00	-2.27	-2.1	0.00	0.00	0.00	0.0
Heat	8.46	8.58	-1.11	-13.0	0.00	0.00	0.00	0.0
Total	311.84	343.74	-7.78	-2.3	11.40	12.64	-0.25	-2.0

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Additionally to the emission reductions in Table 6.5 above 0.47 million t CO_2 can be reduced in the energy sector in 2020 through the savings of electricity, assuming that it is provided by coal and gas (see Part B, chapter 7).

Economic Aspects

Investment costs for this technology wedge cover the costs of upgrading the insulation of the buildings and for improving the efficiency of the electric lighting. The costs for the insulation are based on a case study by KPC (KPC, 2007) and the investment costs for illumination are calculated based on a payback-period of two years. General assumptions on the concept of total costs and additional costs as well as fuel costs are provided in section 6.1.4.

Table 6.6 summarises the results: Until 2020 143 million € per year are invested to improve the efficiency of the production halls. Operating costs consist just of fuel costs, because the increase in the maintenance costs is insignificant. The total cost savings during the operating phase from the more efficient insulation are 16 million € in the first year; following the linear diffusion path assumed for this technology wedge cost savings increase to 171 million € in 2020.

Table 6.6: Technology Wedge P-1: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		143	143	143	143	143	143	143	143	143	143	143
Additional Costs		143	143	143	143	143	143	143	143	143	143	143
Operating costs							n.a.					
Additional Costs		-16	-31	-47	-62	-78	-94	-109	-125	-140	-156	-171

Source: Own calculations based on KPC (2007). – n.a. is not available.

Table 6.7 presents the disaggregation of the investment costs. A large share of the investment stimulates economic activity as it accrues mainly in the construction sector.

Table 6.7: Technology Wedge P-1: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	87.0	4.0	87.0	4.0
Other business services	7.0	0.0	7.0	0.0
Basic metals	5.0	4.0	5.0	4.0
Machinery and equipment n.e.c	1.0	1.0	1.0	1.0
Total	100.0	9.0	100.0	9.0

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs follows the assumptions and data from the Styrian Climate Protection Plan (Land Steiermark, 2010).

Cost appraisal

Based on data for the investment and operating phase for the technology wedge P-1 the user costs of capital for the refurbishing of one m² of a manufacturing hall were analysed. The figures are calculated by using a case study with the following key data:

- Hall area: 13,400 m²
- Total costs: 714,351 €
- Thermal energy demand before action was taken: 127,5 kWh/m²
- Energy savings through the refurbishment: 65 kWh/m²

In Table 6.8 the inputs for the cost appraisal as well as the results are shown. The parameters for manufacturing halls differ from the assumptions for the building sector (described in Part B, chapter 5), because the building types are incommensurable.

For the refurbishment of 1 m² hall area, the investment costs are 53.31 €. This investment causes an energy saving of 65 kWh/m² per year for an assumed service life of 25 years.

In order to illustrate the sensitivity of the results with respect to the interest rate, two alternatives are calculated, the alternative A with an assumed real interest rate of 5% and alternative B with an interest rate of 2.5%.

With an interest rate of 5%, the user costs of capital are 4.8 €/m² p.a., this results in total costs of 9.00 € for 1 m² refurbished building area p.a. For the Alternative B the user costs of capital are 3.5 €/m² p.a. All of the additional costs are caused by the refurbishment.

Table 6.8: Cost appraisal refurbishing of a manufacturing hall with alternative interest rates

Refurbishing buildings		2010	2020
Unit Activity	m^2		
Investments			
Service life	years	25	25
Interest rate	% p.a.	5.0	2.5
Investment price	€/m2	53.31	53.31
User cost of capital	***€/m2 p.a.***	***4.80***	***3.47***
Operating			
Energy flow non-refurbished	kWh p.a.	127.50	127.50
Energy flow refurbished	kWh p.a.	62.50	62.50
Energy price (mix)	€/MWh	67.55	67.55
Energy cost non-refurbished	€/m2 p.a.	8.61	8.61
Energy costs refurbished	*€/m2 p.a.*	*4.22*	*4.22*
Energy cost savings	***€/m2 p.a.***	**4.39**	**4.39**
Total			
Total cost non-refurbished	*€/m2 p.a.*	*8.61*	*8.61*
Total costs refurbished	*€/m2 p.a.*	*9.02*	*7.69*
Additional costs	***€/m2 p.a.***	***0.41***	***-0.93***

Source: Own calculations.

6.2.2 Technology Wedge P-2: Process Intensification and Process Integration

The technology wedge "Process Intensification and Process Integration" is an "efficiency wedge". That means a reduction of greenhouse gas emissions through the reduction of energy demand. The characteristics of Technology Wedge P-2 are shown in Table 6.9.

Table 6.9: Summary Table for Technology Wedge P-2

Process Intensification and Process Integration	
Reducing of the energy demand	38.38 PJ of the energy will be reduced in 2020*
Energy service	Production output increases by 23% by 2020
Technology	Process intensification, use of waste heat
Diffusion path	Linear
Total investment	2,217 million € by 2020
Additional operating costs	-739 million € in 2020
Emission reduction*	1.489 million t CO_2 in 2020

* Compared to reference scenario.

Process intensification is an approach to process and plant design, development and implementation. It is a subset of Green Chemistry and Engineering and focuses on the goal of sustainable development. The concept was originally pioneered in the 1970s by Colin Ramshaw and his co-workers at The Imperial Chemical Industries, where process intensification was defined as a "reduction in plant size by at least a factor 100" (Reay et al., 2008).

There are no clear boundaries between the concepts of process intensification and the general approaches of process optimisation. Only the approach, how the main goals of reduction – energy as well as resources and consequently also greenhouse gas emissions – could be achieved, is different. Unlike process optimisation, which focuses on the improvement of established systems, process intensification creates new processes and structures. Therefore, energy and emission reduction potentials in manufacturing, especially in the sectors with Gordian process structures, not only come from the development of new technologies, but also from new processes and structures using existing technologies. Solutions which are accomplished by process intensification are tailored to particular needs.

In the European Roadmap for Process Intensification, which was developed by the Dutch Senter Novem (Senter Novem, 2007) the energy reduction potentials for different production areas and time periods are shown. Due to this information two relevant sectors have been chosen for the forecast horizon of the project.

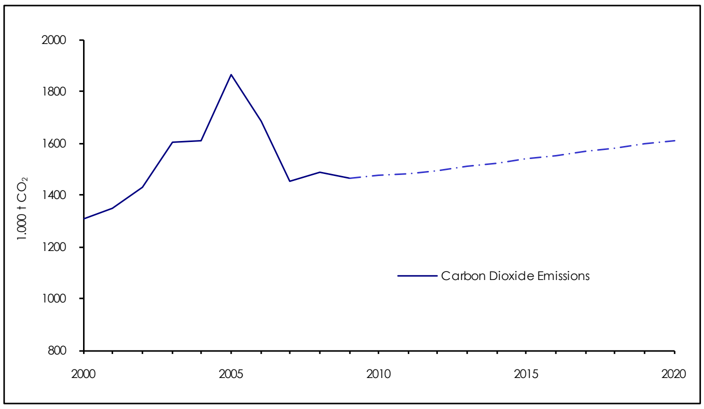
Significant reduction potentials show for the following sectors:

- chemical and petrochemical industries
- food, tobacco and beverages production

These two blocks of industry have complex production patterns which include various thermal processes. Process intensification minimises the size and number of the equipment, reduces the energy intensive structures and uses internal energetic gains.

This concept is mainly useful in sectors with intricate production structures, because the reduction is a result of the restructuring and redefinition of these. Therefore the process intensification has noteworthy CO_2 reduction potentials in the Austrian industry, especially in the food industry and in chemical production. Figure 6.19 shows the reference scenario for CO_2 emissions in these two sectors, if no action is taken.

Figure 6.19: CO_2 emissions of the sectors food, tobacco and beverages and chemicals and petrochemicals – reference scenario



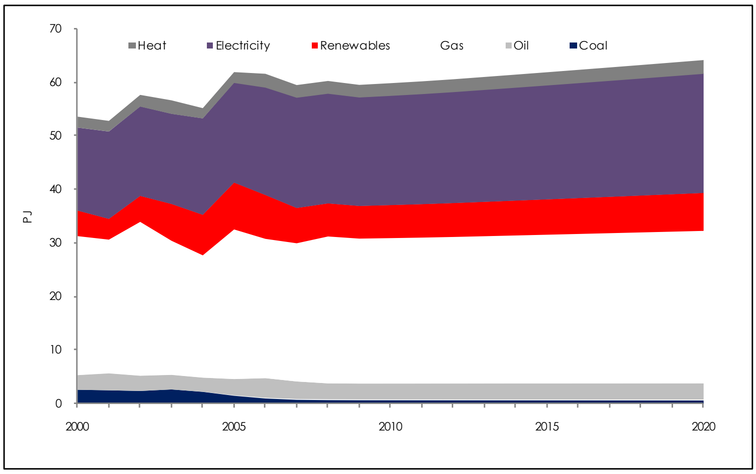
Source: Statistics Austria (2009a, b); own calculations.

Emissions are calculated based on the Austrian energy balances using UNFCCC emission factors. Figure 6.20 shows the development of final energy demand of the sectors food, tobacco and beverages plus chemical and petrochemical from 2000 up to 2020 according to the EnergyTransition reference scenario. In the reference scenario energy demand in these two sectors will rise by 20% between 2000 and 2020. Natural gas accounts for the largest share in final energy consumption, like in general in the manufacturing sector. Also other trends like the decline of emission intensive energy sources (e.g. coal) are identifiable. There is also an above-average share of electricity demand in the two sectors considered.

Final energy demand of the two sectors is distributed as follows (see Figure 6.20):

- 35% for food, tobacco and beverages production
- 65% for chemical and petrochemical industries

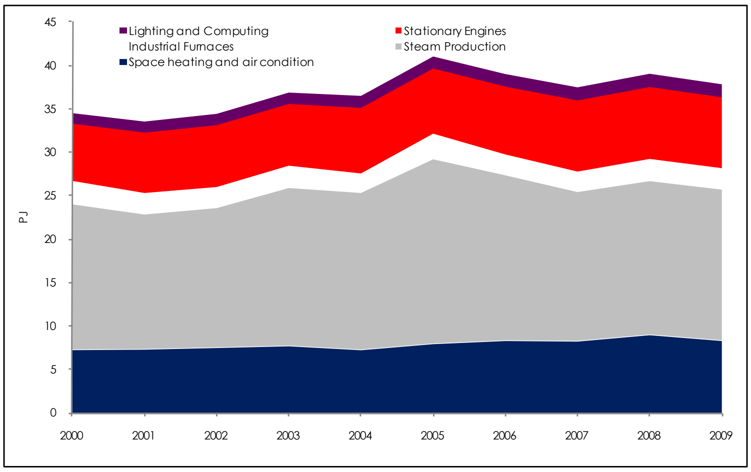
Figure 6.20: Final energy demand of the sectors; food, tobacco and beverages and chemicals and petrochemicals by energy source – reference scenario



Source: Statistics Austria (2009a, b); own calculations.

An analysis of current energy use patterns of the chemicals and petrochemicals sector is provided in section 6.1. In Figure 6.21 the development of final energy consumption of the sector by use category is shown.

Figure 6.21: Development of final energy consumption in the chemical and petrochemical sector by use category



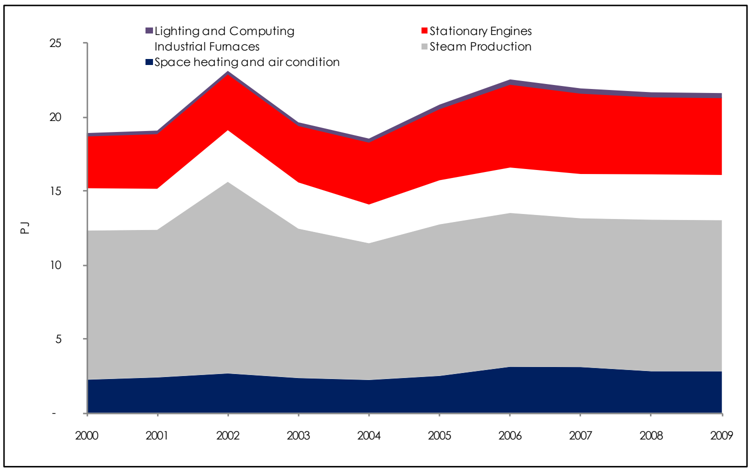
Source: Statistics Austria (2009a, b).

Most of the energy used is thermal energy and especially used for the production of steam. This initial situation is suitable for a reduction through process intensification, because the specific production costs for the thermal energy provided by steam are high. Therefore the payback time for investment in process intensification could be shortened.

The reasons for the higher costs are caused by the steam system, because a steam boiler requires a lot of maintenance and also a specially qualified boiler attendant.

Through these cost reductions, the reduction of greenhouse gases gets a profitable payback time. In the food, tobacco and beverages sector (Figure 6.22) also a high amount of steam is needed. Like in the chemical industry and in manufacturing in general most of the energy is thermal. Energy is also used to provide mechanical energy services. Final energy consumption for these energy services is included in the useful energy category stationary engines of the Useful Energy Balances of Statistics Austria.

Figure 6.22: Development of the useful energy categories in the food, tobacco and beverages sector



Source: Statistics Austria (2009a, b).

As aforementioned, process intensification is associated with the development of new technologies. Therefore the reduction potentials are rising with the time horizon. For an illustration, examples for energy savings potentials based on process intensification are listed below.

Energy efficiency potential of PI technologies for food production within 30-40 years

- 10% volumetric heating to reduce product contact
- 20% improved equipment surface
- 15-30% alternative energy transfer (e.g. UV light, radio frequency and pulse electric fields)
- 20% improved module design (e.g. in membranes processes)

The time horizon until 2020 for which the reduction potential is calculated must deal almost entirely with yet available technologies. On the one hand this option brings already a profitable reduction, but on the other hand it limits the potential compared to newly available future technologies.

Implementation of the energy transition methodology for Technology Wedge P-2

In the project EnergyTransition all technology wedges are documented in a common framework as presented in Part B, chapter 3 to ensure their comparability. Table 6.10 shows the energy indicators and their development in the technology wedge compared to 2008.

Table 6.10: Technology Wedge P-2: Summary of energy indicators

Process Intensification and Process Integration	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	-16	84
Final Energy Intensity (f)	100	-3	97
Final Energy (F)	100	0	100

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	6.4	0.0	6.4
Oil	10.5	0.0	10.5
Gas	33.3	0.0	33.2
Renewables	15.5	0.0	15.5
Electricity	31.6	0.0	31.7
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

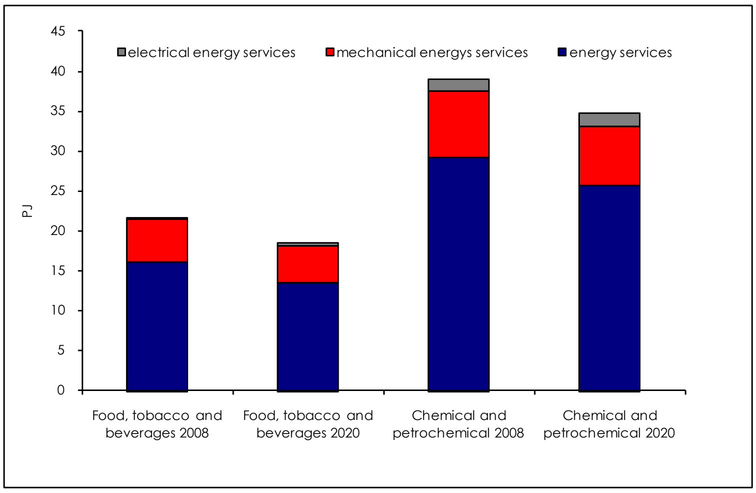
Source: Own calculations.

For the manufacturing sector the energy service is approximated by output which is assumed to rise until 2020 by 23% between 2008 and 2020. Useful energy intensity and respectively useful energy demand decreases because of a change of the process structures through the implementation of newly designed processes. The decrease of final energy demand due to the internal use of waste heat is mirrored in the change of final energy intensity. There are only small changes in the fuel mix because the savings influence all energy sources. Given that, the restructuring of the processes has impacts on several energy services: thermal, mechanical and electrical energy services are considered.

In Table 6.10 the development is shown compared to total energy demand of the manufacturing sector; therefore the savings in some sectors seem to have a marginal contribution to overall energy demand changes in total manufacturing.

Energy savings through process intensification hence accrue to the useful energy categories steam production, stationary engines and industrial furnaces. Figure 6.23 shows the difference in final energy consumption by use category in the two blocks of production sectors between 2008 and 2020.

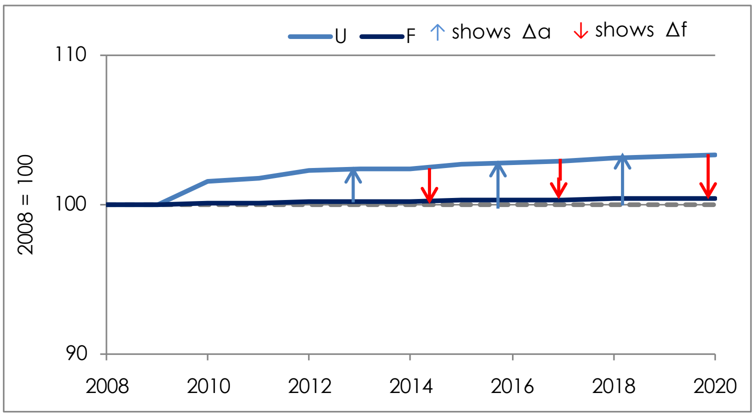
Figure 6.23: Final energy consumption by useful energy category in 2008 and in 2020 after reduction through process intensification



Source: Own calculations based on Statistics Austria (2009b).

Figure 6.24 shows the development of useful and final energy intensity based on the EnergyTransition methodology, see Part B, chapter 3. The light blue line shows increases in sectoral energy demand induced by the rising energy service. This development is partly compensated by improvements in final energy intensity illustrated by the red arrows. The combined effect of changes in energy service and useful energy intensity (Δa) and final energy intensity (Δf) is a slight increase of final energy consumption by 2020 compared to 2008 illustrated by the dark blue line.

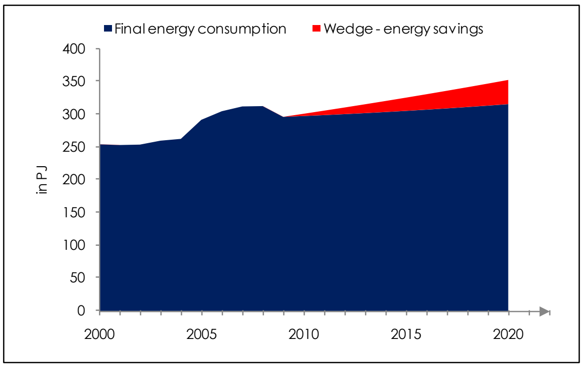
Figure 6.24: Technology Wedge P-2: Effects on useful energy and final energy[1]

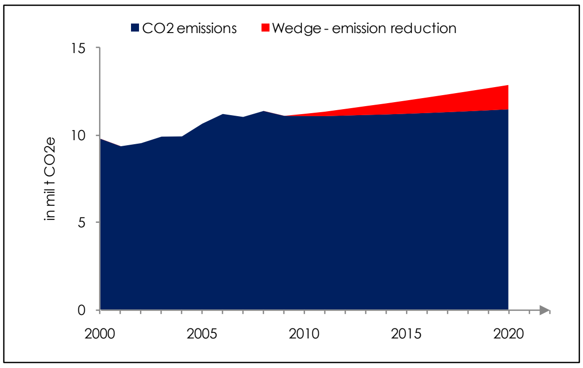


Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

Figure 6.25 shows the reduction of final energy consumption and emissions, which will be achieved by a comprehensive implementation of process intensification in the sectors food, tobacco and beverages and chemicals and petrochemicals compared to the EnergyTransition reference scenario. Energy and emissions savings of Technology Wedge P-2 are again presented in relation to the EnergyTransition reference scenario for the whole manufacturing sector to ensure a comparability of the technology wedges.

Figure 6.25: Technology Wedge P-2: Effects on final energy demand (right) and on CO_2 emissions (left)





Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

The technology wedge leads to lower fossil fuel demand in 2020 of 28 PJ compared to the reference scenario. With respect to emissions 1,489 kt CO_2 are emitted less in 2020 compared to the reference scenario (see Table 6.11).

Table 6.11: Technology Wedge P-2: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	19.89	-2.41	-12.1	1.99	1.99	-0.23	-11.8
Oil	32.64	32.82	-5.63	-17.1	2.41	2.41	-0.44	-18.2
Gas	103.69	99.40	-14.85	-14.9	5.70	5.47	-0.82	-14.9
Renewables	48.36	47.22	-8.34	-17.7	1.29	1.53	0.00	0.0
Electricity	98.69	104.54	-6.72	0.0	0.00	0.00	0.00	0.0
Heat	8.46	9.26	-0.43	0.0	0.00	0.00	0.00	0.0
Total	311.84	313.14	-38.38	-12.3	11.40	11.39	-1.49	-13.1

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Additionally to the emission reductions in Table 6.11, 1.38 million t CO_2 can be reduced in 2020 in the energy sector through the savings of electricity, assuming that it is provided by coal and gas. Further information on the reductions and their calculation is provided in Part B, chapter 7 on energy supply.

Economic Aspects

All investment costs of this efficiency wedge are additional costs (see section 6.1). This wedge includes several types of machinery, because there is no ubiquitous solution to changes of process structures in different industry sectors. Therefore the investment costs were calculated based on assumptions for the payback time, which assumes that investment changes of process internal structures will only be realised if their maximum payback time will not exceed three years. So the investment costs are calculated based on their savings in fuel costs through the payback time.

Table 6.12: Technology Wedge P-2: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		202	202	202	202	202	202	202	202	202	202	202
Additional Costs		202	202	202	202	202	202	202	202	202	202	202
Operating costs						n.a.						
Additional Costs		-67	-134	-202	-269	-336	-403	-470	-538	-605	-672	-739

Source: Own calculations. – n.a. is not available.

Due to the assumed continuous (linear) investment in the sector, the saving in operating costs increases every year. It is also presumed that the energy reduction per investment is constant over the period considered. A high share of investment stimulates regional economic activity because the construction sector is mainly affected (Table 6.13)

Table 6.13: Technology Wedge P-2: Disaggregation of Investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	78.0	3.9	78.0	3.9
Other business services	8.0	4.0	8.0	4.0
Basic metals	4.0	3.2	4.0	3.2
Machinery and equipment n.e.c	10.0	5.2	10.0	5.2
Total	100	16.3	100	16.3

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

6.2.3 Technology Wedge P-3: Energy efficient engines

The technology wedge "energy efficient engines" implies the replacement of outworn electrical motors. Table 6.14 shows the main characteristics of this technology wedge.

Table 6.14: Summary Table for Technology Wedge P-3

Energy efficient engines	
Reduction of energy demand	9.964 PJ reduced by energy efficient engines in 2020*
Energy service	Production output increases by 23% by 2020
Technology	Installation of energy efficient engines
Diffusion path	Linear
Total investment	700 million € by 2020
Additional operating costs	-350 million € in 2020
Emission reduction*	0.056 million t CO_2 in 2020

* Compared to reference scenario.

All activities and processes in the manufacturing sector depend heavily on electric motors, given that most operations that require a moving part have an electric motor in the background. A small number of diesel and gas motors are also used in the manufacturing sector but these are limited to special applications. In the industrial sector the electric motors are used in a wide variety of applications including compacting, fans, cutting, grinding, mixing, pumps, materials conveying, air compressors and refrigeration. Motors are also used widely in the commercial sector for air conditioning, ventilation, refrigeration, water pumping, lifts and escalators.

There is a considerable difference in performance between standard and energy efficient motors. Improved design, high quality materials and better manufacturing techniques enable energy efficient motors to perform more work per unit of electricity consumed. The motor manufacturers offer longer warranties for more efficient models due to improved performance, better insulation, higher service factors, less vibration, etc.

The use of energy efficient motors has been widely recognised as an important energy saving option and therefore a high emissions mitigation potential. Motive power accounts for about 600 TWh/year[31] in the European Union and with energy efficiency upgrading actions it is possible to reduce the consumption by one third of that value in a cost-effective manner.

The cost effectiveness of an energy-efficient motor depends on a number of factors; this is why it is necessary to assess each case specifically. Normally the most important variables to determine the cost effectiveness of an industrial size motor are: motor price, efficiency rating, annual hours of use, energy rates, the company's payback criteria and the costs of installation and downtime.

The normal way to repay the extra cost of an energy efficient motor is through energy savings. In typical industrial applications energy-efficient motors are cost effective when they operate more than 4,000 hours a year, given a 2-year simple payback criterion. It also has to be taken into consideration that motors are sized for a specific load interval. The further one

[31] European motor system database – EuroDEEM, (2010).

moves away from the specified operating conditions the more inefficient the motor will be. In some cases it is necessary to oversize the motor in order for it to stand peak load conditions but in that case one might consider using a correctly sized motor backed up by a smaller motor.

Depending on the use of the electric motors there are differences in the payback period one should seriously consider. Currently inefficient motors that run continuously (8,000 hours a year or more) should be replaced as soon as possible given that these offer rapid payback times through energy savings and improved reliability. Another class of motors comprises the ones that should be replaced with an energy efficient model but not before their time of failure. The user has to decide when to buy a new more efficient motor: either before the existing motor is out of order or beforehand as backup device. This choice depends on how quickly an energy-efficient motor can be obtained through suppliers, how quickly a failed motor must be replaced and how many motors of the same size and type are used in the respective facility.

It is possible to evaluate motor efficiency with a free EuroDEEM International Software. This software is a tool which not only includes databases of various Electric Motor System components (i.e. motors, end-use devices as pumps, fans, etc., coupling & transmission, control (VSD's) and power quality devices) but also associated modules which should allow the user to carry out system analysis and make him/her aware of system inefficiencies, identify losses and suggest possible solutions.

Implementation of EnergyTransition methodology for Technology Wedge P-3

The potential is calculated according to the useful energy category stationary engines. There are appreciable potentials for all manufacturing sectors. Only the construction sector with its high amount of oil fuelled stationary engines is partly excluded from the calculations because a radical replacement of the construction equipment until 2020 is improbable.

Table 6.15: Technology Wedge P-3: Summary of energy indicators

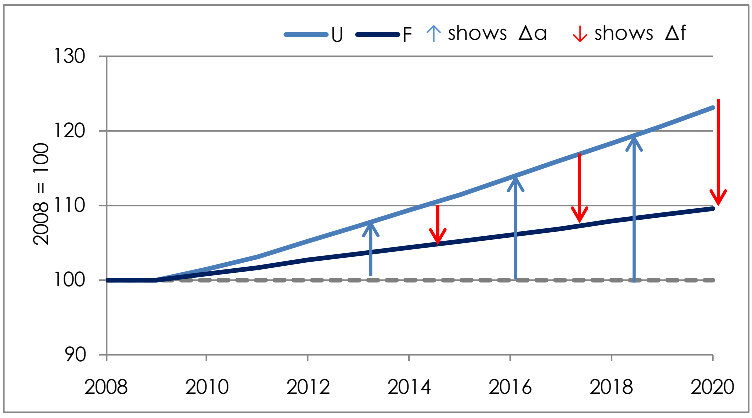
Energy efficient engines	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	0	100
Final Energy Intensity (f)	100	-11	89
Final Energy (F)	100	10	110

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	6.4	0.0	6.4
Oil	10.5	0.0	10.5
Gas	33.3	0.1	33.3
Renewables	15.5	0.0	15.5
Electricity	31.6	-0.2	31.5
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

Source: Own calculations.

Table 6.15 shows the development of the energy indicators. The energy service (S) is defined as economic output which increases continuously over time. Due to an increase in efficiency the final energy intensity (f) falls by 11% until 2020. As Technology Wedge P-3 addresses exclusively energy efficiency improvements of engines, no changes in useful energy intensity (u) are considered. The changes of the fuel shift are mainly caused by the savings in electricity.

Figure 6.26: Technology Wedge P-3: Effects on useful energy and final energy[1]

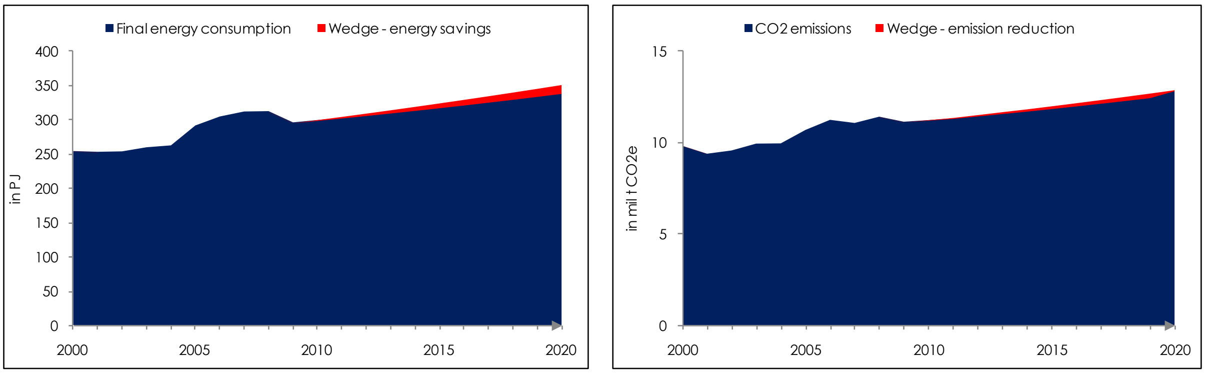


Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

In Figure 6.26 the development of the energy indicators and the interrelations between them are shown. An increase in energy service at constant useful energy intensity (Δa, illustrated by the blue arrows) is partly compensated by an increase in final energy intensity (Δf, illustrated by the red arrows).

Figure 6.27 presents the energy savings potential and the potential of this technology wedge for a reduction of carbon dioxide emissions compared to the EnergyTransition reference scenario. Based on the international guidelines for calculating emissions, emissions stemming from electricity demand are accounted for in the energy sector and not in manufacturing.

Figure 6.27: Technology Wedge P-3: Effects on final energy demand (right) and on CO_2 emissions (left)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 6.16 presents the results of Technology Wedge P-3. The reduction of oil, gas and electricity demand is caused by the replacement of old engines through new ones. The total reduction in energy demand origins from the fact that new engines are up to 35% more efficient than the partly 40 years old machinery. The main part of the equipment is driven by electricity therefore the savings in this category accounts for the main part.

Table 6.16: Technology Wedge P-3: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	22.30	0.00	0.0	1.99	2.22	0.00	0.0
Oil	32.64	37.73	-0.72	-1.9	2.41	2.79	-0.06	-2.0
Gas	103.69	114.25	-0.01	0.0	5.70	6.28	0.00	0.0
Renewables	48.36	55.56	0.00	0.0	1.29	1.53	0.00	0.0
Electricity	98.69	102.02	-9.24	0.0	0.00	0.00	0.00	0.0
Heat	8.46	9.69	0.00	0.0	0.00	0.00	0.00	0.0
Total	311.84	341.55	-9.96	-2.9	11.40	12.83	-0.06	-0.4

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Additionally to the emission reductions in the Table above 1.9 million t CO_2 can be reduced in the energy sector in 2020 through the savings of electricity, assuming that it is produced with coal and gas. Further information on the reductions and their calculations is provided in Part B, chapter 7 on energy supply.

Economic Aspects

All the investment costs of this efficiency wedge are additional costs (see section 6.1). The investment costs were calculated on a payback time of three years. Investment decisions in order to increase energy efficiency are usually not realised if their payback time is longer than three years. So the investment costs were calculated based on their savings in fuel costs through the payback time.

Table 6.17: Technology Wedge P-3: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		64	64	64	64	64	64	64	64	64	64	64
Additional Costs		64	64	64	64	64	64	64	64	64	64	64
Operating costs							n.a.					
Additional Costs		-32	-64	-95	-127	-159	-191	-223	-254	-286	-318	-350

Source: Own calculations. – n.a. is not available.

Caused by the continuous (linear increasing) investment in the sector the savings in operating costs increase every year. As the energy reduction does not change over the period considered, the operating costs follow a linear path (see Table 6.17).

Table 6.18 shows the disaggregation of the investment costs. The only production sector on which the investment costs have a considerable impact is machinery and equipment, caused by an increased production of new engines.

Table 6.18: Technology Wedge P-3: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	10.0	0.5	10.0	0.5
Other business services	7.0	0.4	7.0	0.4
Basic metals	5.0	4.0	5.0	4.0
Machinery and equipment n.e.c	78.0	40.6	78.0	40.6
Total	100.0	45.4	100.0	45.4

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

6.2.4 *Technology Wedge P-4: Combined Heat and Power*

In this technology wedge gas burners are replaced by gas based combined heat and power plants (CHPs). Table 6.19 presents the main characteristics of this technology wedge.

Table 6.19: Summary Table for Technology Wedge P-4

Combined Heat and Power	
Production of electricity by cogeneration	9.9 PJ of electricity produced by natural gas-fuelled cogeneration plants
Energy service	Not applicable
Technology	Combined heat and power generation
Diffusion path	Linear
Total investment	331 million € by 2020
Operating costs	44 million € in 2020
Additional operating costs	-108 million € in 2020
Emission increase*	0.96 million t CO_2 in 2020

* Compared to reference scenario.

CHP, also known as cogeneration, is the simultaneous production of electricity and heat from a single fuel source such as biomass/biogas, natural gas, coal or oil. The hallmark of well designed CHP systems is an increase in the efficiency of fuel use compared to the separate production of electricity and heat. By using waste heat recovery technology to capture a significant proportion of heat created as a by-product in electricity generation, CHP systems typically achieve total system efficiencies of 60% to 80% for producing electricity and thermal energy. These efficiency gains improve the economics of using fuels and produce other environmental benefits as well. Specific benefits depend on the intended use and fuel source, but often include reduced greenhouse gas emissions, energy cost savings, local economic development, waste reduction and the security of domestic fuel supply.

CHPs are being used for quite some years in big plants and industries. The industrial sector currently produces both steam or hot water and electricity from biomass in CHP facilities in the paper, chemical, wood products, and food-processing industries. These industries are major users of biomass and utilising the heat and steam in their processes can improve energy efficiency by more than 35%. The wood products industry can normally generate more than half of their own energy need from woody waste products and other renewable sources (e.g., wood chips, black liquor). Other sectors mainly use gas or oil for cogeneration.

In the recent past Micro CHP systems are developed for houses and small businesses. Normally these are units ranging from 1 to 6 kW_e. The development of Mini CHP systems (less than 500 kW_e) is intended for buildings and medium size businesses. The engines used in the CHP units for producing electricity can be internal combustion or Stirling (also called external combustion) engines. Other types of generation technologies, such as fuel cells, have not reached the commercialisation stage. Micro-CHPs as residential-sized CHP systems are usually run on natural gas or diesel.

Implementation of EnergyTransition methodology for Technology Wedge P-4

The potential for Technology Wedge P-4 is based on the demand for natural gas, which is used to provide thermal energy on a temperature level from 100°C up to 400°C. Like in every substitution wedge, old equipment is replaced through new technology. In Technology Wedge P-4 old gas burners are exchanged by new CHP systems.

Table 6.20: Technology Wedge P-4: Summary of energy indicators

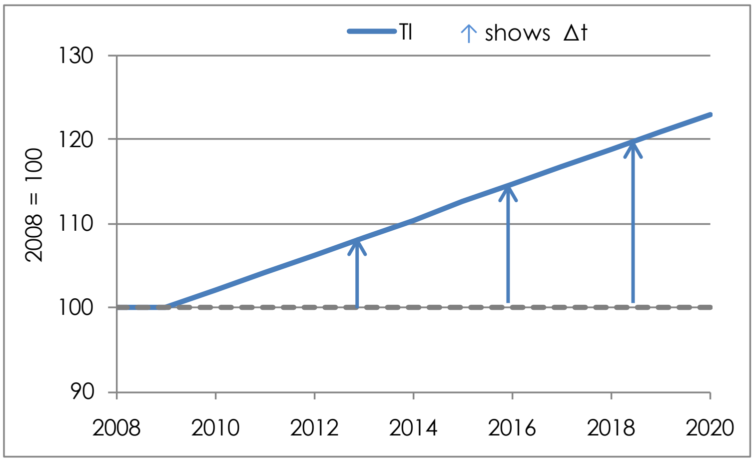
Implementation of gas CHPs instead of gas burners	2008 2008=100	2020/2008 %	2020 2008=100
Transformation Output (TO)	**100**	**34**	**134**
Gas CHP	100	67	167
Transformation Efficiency (e)	**100**	**9**	**109**
Gas CHP	100	3	103
Transformation Input (TI)	**100**	**23**	**123**
Gas CHP	100	62	162

Source: Own calculations.

Table 6.20 shows the changes of the energy indicators according to the EnergyTransition methodology for electricity and heat supply. Increases in transformation efficiency are caused by the higher effectiveness of the new CHPs. Through a comprehensive implementation of CHP plants instead of gas burners transformation input rises up to 162 (2008 = 100) for the gas CHPs. The transformation output goes up to 167 caused by the increase in transformation efficiency.

Figure 6.28 shows the development of transformation input in Technology Wedge P-4 over time according to the EnergyTransition methodology as described in Part B, chapter 3. Through a comprehensive implementation of CHP plants energy production of autoproducers and transformation input increase. Due to the higher efficiency of CHPs, compared to single generation of coal and gas, efficiency of overall energy generation by autoproducers, however, increases. This combined effect of changes in transformation input and efficiency is depicted by the blue arrows; the development of transformation input is illustrated by the dark blue line.

Figure 6.28: Technology Wedge P-4: Effects on transformation input[1]



Source: Own illustration. - Δt describes the combined effect of changes in transformation output and transformation efficiency. TI is transformation input.

To make the potentials and reductions visible, they are shown compared to the EnergyTransition reference scenario. There exists a potential for increased use of natural gas in CHPs which translates into a reduction of the electricity demand but also into an increase of the CO_2 emissions in the manufacturing sector.

Table 6.21 presents the results of Technology Wedge P-4, the replacement of natural gas burners through CHPs. Transformation input of the category CHPs increases by 49% compared to 2008; this causes an increase in the CO_2 emissions of 17% for autoproducers in the manufacturing sector.

Table 6.21: Technology Wedge P-4: Effects on transformation input and CO_2 emissions

Energy Source	Transformation Input				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	15.47	17.65	0.00	0.0	1.50	1.71	0.00	0.0
Oil	7.61	8.23	0.00	0.0	0.74	0.64	0.00	0.0
Gas	20.09	30.03	-9.94	-49.5	1.11	1.65	-0.55	-49.5
Total	43.17	55.91	-9.94	-21.6	3.34	4.00	-0.55	-15.8

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Additionally to the emission increases in the manufacturing sector given in Table 6.21, 0.65 million t CO_2 can be reduced in the energy sector in 2020 through savings of electricity assuming that it is produced with coal and gas. Further information on the reductions and their calculation is provided in Part B, chapter 7 on energy supply.

Economic Aspects

The investment costs for Technology Wedge P-4 are based on the investment costs for a CHP plant instead of a natural gas burner. The concept of total costs and additional costs as well as fuel costs is described in chapter 6.1.3.

Table 6.22 summarises the results: Until 2020 30 million € per year are invested for the installation of CHPs assuming a linear diffusion path for this technology wedge. The total cost savings during the operating phase from the substitution of gas burners by CHPs are 4 million € in the first year; these cost savings increase linearly to 108 million € in 2020.

Table 6.22: Technology Wedge P-4: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		30	30	30	30	30	30	30	30	30	30	30
Additional Costs		29	29	29	29	29	29	29	29	29	29	29
Operating costs		6	13	19	25	32	38	44	51	34	39	44
Additional Costs		-4	-8	-12	-16	-20	-24	-28	-32	-81	-94	-108

Source: Own calculations.

Operating costs consist of fuel costs and maintenance costs; the contribution of these cost categories is shown in Table 6.23.

Table 6.23: Technology Wedge P-4: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional costs in %
Fuel costs gas	92.0	92.0
Maintenance	8.0	8.0
Total	100.0	100.0

Source: Own calculations.

Table 6.24 shows the disaggregation of the investment costs. The only production sector on which the investment costs have a considerable impact is machinery and equipment due to a rise in the production of CHP technologies.

Table 6.24: Technology Wedge P-4: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	8.0	0.0	8.0	0.0
Other business services	8.0	0.0	8.0	0.0
Basic metals	4.0	3.0	4.0	3.0
Machinery and equipment n.e.c	80.0	42.0	80.0	42.0
Total	100.0	45.0	100.0	45.0

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

6.2.5 Technology Wedge P-5: Substitution of fossil energy sources with high emission-coefficients

This technology wedge analyses the substitution of emission intensive fossil energy sources by fossil fuels with a lower emission factor. Table 6.25 presents the key features of this technology wedge.

Table 6.25: Summary Table for Technology Wedge P-5

Substitution of fossil energy sources with high emission-coefficients	
Substitution of oil and coal based thermal energy	22.9 PJ of thermal of coal and oil based energy substituted by gas based energy*
Energy service	Production output increases by 23% by 2020
Technology	Gas boiler
Diffusion path	Linear
Total investment	65 million € by 2020
Operating costs	423 million € in 2020
Additional operating costs	-73 million € in 2020
Emission reduction*	0.8 million t CO_2 in 2020

* Compared to reference scenario.

The utilisation of coal and oil has declined steadily over the last 10 years. Especially the share of coal in final energy demand of the manufacturing sector has fallen from 9% in 2000 to 6% in 2008. This is nearly 2 PJ less coal in 2008 compared to 2000.

There are several reasons for this switch to mainly natural gas with the reduction of CO_2 emissions as the most relevant one. For example 1 TJ of hard coal exhausts 94 t of CO_2, while 1 TJ of natural gas just emits 55 t CO_2.

This is of course an advantage of natural gas but in case of rigorous cost-effectiveness other benefits count. The state of the art of natural gas burners has already reached a high degree of efficiency and the available technologies are cheap. Compared to oil or coal fired systems there is no infrastructure needed to store the fuels. The quality of the gas provided is already aligned to the prescriptive emission limits; therefore no treatment of the exhaust gases is required.

Nevertheless there is still an unexploited potential for a switch to fossil fuels with lower emission-coefficients. Basically thermal energy is provided by natural gas because there is a wide temperature range achievable.

There are some applications were oil and coal cannot be totally replaced currently. One reason is that it is needed in a chemical reaction. The common example for this case is the reaction between iron and coke in a blast furnace. Another reason is that the technology applications still are not competitive, e.g. in the construction sector where the equipment is driven by oil.

Implementation of EnergyTransition methodology for Technology Wedge P-5

The potential for Technology Wedge P-5 is based on the demand for coal and oil which is used to provide thermal energy. Therefore the demand for coal in the iron and steel production and the demand for oil in the construction sector are not included in the calculations. Like in every substitution wedge, old equipment is replaced by the new technology. In Technology Wedge P-5 old oil and coal furnaces are replaced by new natural gas burners.

Table 6.26: Technology Wedge P-5: Summary of energy indicators

Substitution of fossil energy sources with high emission-coefficients	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	0	100
Final Energy Intensity (f)	100	-9	91
Final Energy (F)	100	12	112

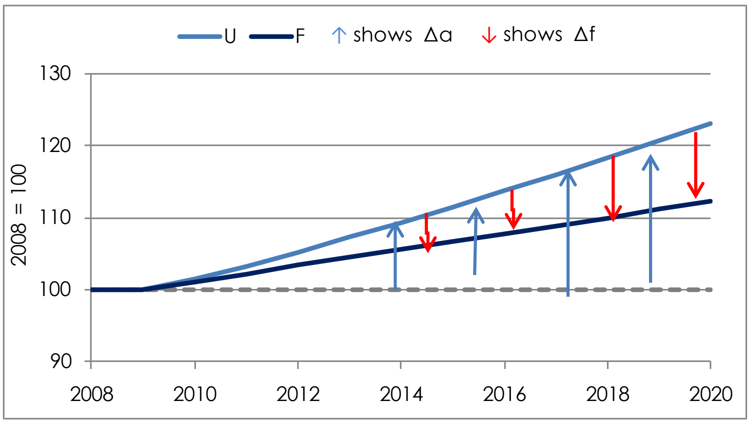
Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	6.4	-0.3	6.1
Oil	10.5	-0.4	10.0
Gas	33.3	0.7	33.9
Renewables	15.5	0.0	15.5
Electricity	31.6	0.0	31.7
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

Source: Own calculations.

In Table 6.26 the energy indicators, like final energy demand, are shown. Due to the exchange of old machinery the efficiency rises and causes a decrease in final energy intensity. For the manufacturing sector, the energy service is approximated by output, which is assumed to rise until 2020. Due to the switch from oil and coal to gas the shares of the energy sources change.

Figure 6.29 shows the development of the useful and final energy intensity according to the methodology as described in Part B, chapter 3. Due to the rising energy service and constant useful energy intensity (as depicted by the blue arrows) useful energy demand increases by 2020. This increase is, however, partly compensated through improvements in final energy intensity illustrated by the red arrows. Nevertheless, final energy demand rises by 12% compared to 2008, which is illustrated by the dark blue line.

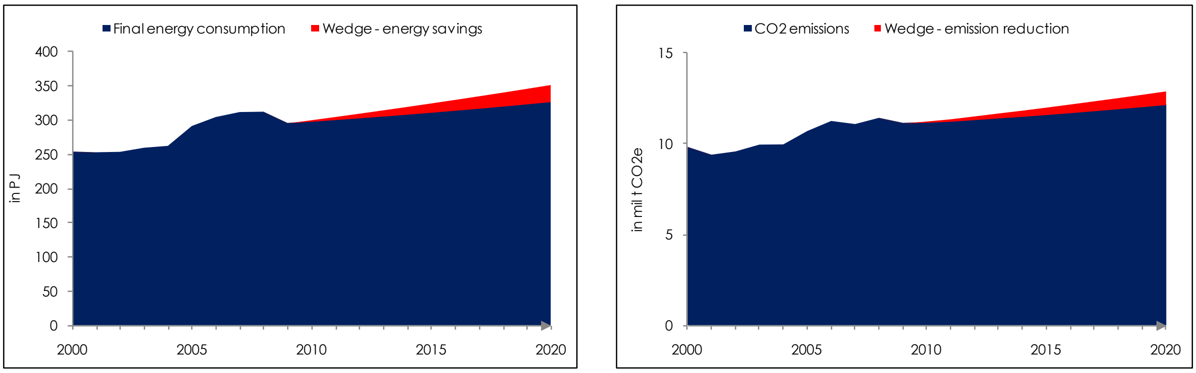
Figure 6.29: Technology Wedge P-5: Effects on useful energy and final energy[1]



Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. Δf describes the effect of changes in final energy intensity. F is final energy consumption. U is useful energy.

To make the potentials and reductions visible, they are shown compared to the EnergyTransition reference scenario. There exists a potential for an increased use of natural gas which translates into a reduction of the demand for oil and coal as well as CO_2 emissions. Figure 6.30 presents the energy reduction potential as well as the potential of Technology Wedge P-5 for reducing carbon CO_2 emissions compared to the EnergyTransition reference scenario.

Figure 6.30: Technology Wedge P-5: Effects on final energy demand (right) and on CO_2 emissions (left)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 6.27 presents the results of Technology Wedge P-5, the reduction of oil and coal is caused by the substitution of natural gas. The total reductions of energy demand originate from the fact that new gas burners are up to 15% more efficient than the old coal and oil furnaces. The reduction of CO_2 emissions is a result of the lower emissions coefficient of natural gas as well as of the savings trough the increase of efficiency.

Table 6.27: Technology Wedge P-5: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	13.14	-9.15	-41.1	2.22	1.33	-0.89	-40.0
Oil	32.64	24.65	-13.79	-35.9	2.85	1.77	-1.08	-37.8
Gas	103.69	135.64	21.38	18.7	6.28	7.46	1.18	18.7
Renewables	48.36	55.56	0.00	0.0	1.53	1.53	0.00	0.0
Electricity	98.69	111.26	0.00	0.0	0.00	0.00	0.00	0.0
Heat	8.46	9.69	0.00	0.0	0.00	0.00	0.00	0.0
Total	311.84	351.52	-1.56	-0.4	12.88	12.10	-0.79	-6.1

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic Aspects

The investment costs for this wedge are based on the investment in natural gas burners instead of oil or coal furnaces. General information to the concept of total costs and additional costs as well as to fuel costs are provided in chapter 6.1.

Table 6.28 summarises the results: Until 2020 6 million € per year are invested for the installation of natural gas burners. Operating costs consist just of fuel costs whereas the contribution of the maintenance costs is insignificant. Constant fuel costs are assumed. The total cost savings during the operating phase from the substitution of coal and oil furnaces by more efficient gas furnaces are 7 million € in the first year; cost savings increase to 73 million € in 2020.

Table 6.28: Technology Wedge P-5: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		6	6	6	6	6	6	6	6	6	6	6
Additional Costs		-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
Operating costs		38	77	115	154	192	231	269	308	346	385	423
Additional Costs		-7	-13	-20	-27	-33	-40	-46	-53	-60	-66	-73

Source: Own calculations.

Table 6.29 shows the disaggregation of the investment costs. The only production sector on which the investment costs have a considerable impact is machinery and equipment.

Table 6.29: Technology Wedge P-5: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	8.0	0.5	8.0	0.0
Other business services	8.0	0.4	8.0	0.0
Basic metals	4.0	3.2	4.0	3.0
Machinery and equipment n.e.c	80.0	41.9	80.0	42.0
Total	100.0	45.9	100.0	45.0

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

6.2.6 *Technology Wedge P-6: Biomass for process-heat*

In this technology wedge thermal energy on low temperature level which was formerly produced by natural gas is substituted by thermal energy from biomass. Table 6.30 shows the main parameters of this wedge.

Biomass is a renewable energy source derived from living or recently living organisms. Usually it is plant matter used for direct incineration and either electricity or heat production. The usual feed stocks for direct incineration are forest residues, yard clippings, wood chips, garbage and biodegradable waste. However, biomass also includes plant or animal matter used for production of fibres or chemicals. It is important to stress that fossil fuels are not biomass and the vital difference between the two is the time scale in which they are produced. Biomass takes carbon out of the atmosphere while it is growing and returns it when it is burned. Therefore if biomass growth and harvesting is managed sustainably it is possible to maintain a closed carbon cycle with no net increase in atmospheric CO_2 levels.

One of the central benefits of biomass is its regional availability and positive impacts for the regional economy. As biomass has a low energy density, long transport routes are ecologically unacceptable.

Table 6.30: Summary Table for Technology Wedge P-6

Biomass for process-heat	
Substitution of gas based thermal energy	11.112 PJ of gas based thermal energy substituted by biomass
Energy service	Production output increases by 23% by 2020
Technology	Biomass heating plant
Diffusion path	Linear
Total investment	386 million € by 2020
Operating costs	58 million € in 2020
Additional operating costs	-143 million € in 2020
Emission reduction*	0.611 million t CO_2 in 2020

* Compared to reference scenario.

Implementation of EnergyTransition methodology for Technology Wedge P-6

The potential for the Technology Wedge P-6 is based on the demand for natural gas, which is used to provide thermal energy. The utilisation of biomass is only cost-effective if the thermal energy demand is on a level under 400 - 500°C. Therefore, the data on the temperature distribution were used for the calculations from the analysis in chapter 6.1. Like in every substitution wedge old equipment is replaced through the new technology. In Technology Wedge P-6 gas burners are exchanged by new biomass furnaces.

Table 6.31 shows the development of the energy indicators according to the methodology as described in Part B, chapter 3. In the table the development is shown compared to total energy demand of the manufacturing sector. Therefore, the savings in only some areas seem to have marginal contribution to overall manufacturing energy demand.

Table 6.31: Technology Wedge P-6: Summary of energy indicators

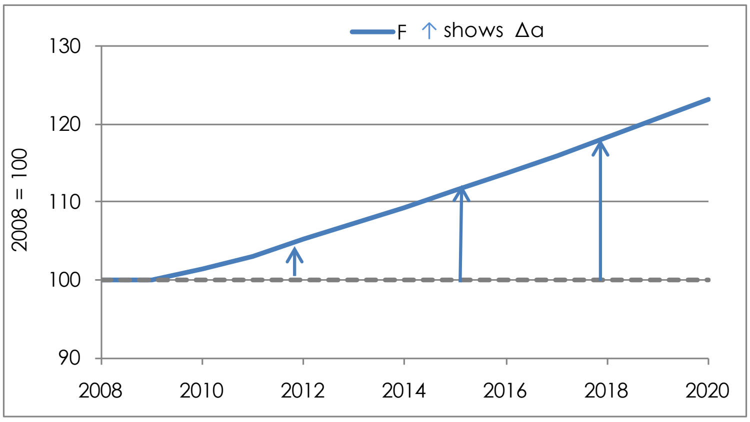
Biomass for process heat	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	0	100
Final Energy Intensity (f)	100	0	100
Final Energy (F)	100	23	123

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	6.4	0.0	6.4
Oil	10.5	0.0	10.5
Gas	33.3	-0.6	32.7
Renewables	15.5	0.6	16.1
Electricity	31.6	0.0	31.6
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

Source: Own calculations.

For the manufacturing sector, the energy service is approximated by economic performance which rises until 2020. Neither useful energy intensity nor final energy intensity change over time because there is no change in the degree of efficiency. This mirrors that the new biomass furnaces are as efficient as the old natural gas burners. Changes in the fuel mix are induced by this technology wedge.

Figure 6.31: Technology Wedge P-6: Effects on final energy[1]

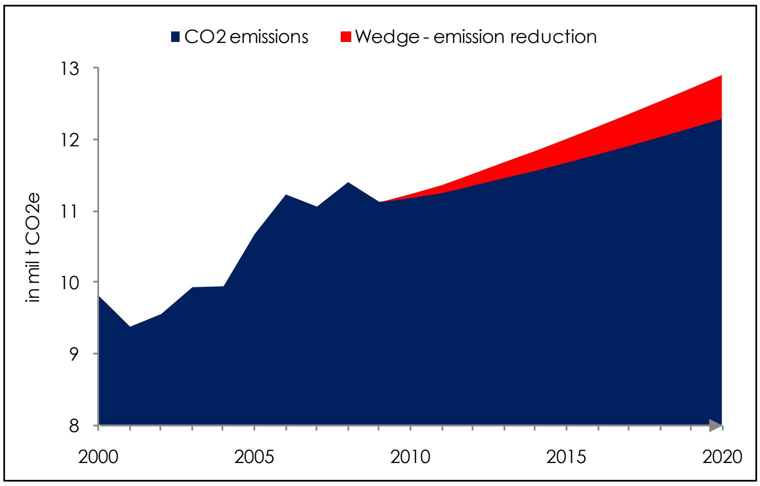


Source: Own illustration. – [1] Δa describes the combined effect of changes in energy services and useful energy intensity. F is final energy consumption.

Figure 6.31 shows the development of final energy consumption based on the EnergyTransition methodology. Due to rising energy services and constant energy intensities final energy demand increases until 2020 as illustrated by the blue line. The increase in final energy consumption is hence equal to the increase in energy service approximated by output.

Figure 6.32 shows the potential of this technology wedge for a reduction of carbon dioxide emissions. The graph shows the emissions compared to the reference scenario.

Figure 6.32: Technology Wedge P-6: Effects on CO_2 emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 6.32 presents the results of Technology Wedge P-6. The reduction of natural gas is caused by the comprehensive substitution through biomass. There is no increase in efficiency included because only old gas burners with a lower efficiency are replaced through new biomass furnaces. The reduction of CO_2 emissions by 0.6 million t in 2020 compared to the reference scenario results from the substitution of fossil fuel by a CO_2 neutral energy source.

Table 6.32: Technology Wedge P-6: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	22.30	0.00	0.0	1.99	2.22	0.00	0.0
Oil	32.64	38.45	0.00	0.0	2.41	2.85	0.00	0.0
Gas	103.69	103.14	-11.11	-10.8	5.70	5.67	-0.61	-10.8
Renewables	48.36	66.67	11.11	16.7	1.29	1.53	0.00	0.0
Electricity	98.69	111.26	0.00	0.0	0.00	0.00	0.00	0.0
Heat	8.46	9.69	0.00	0.0	0.00	0.00	0.00	0.0
Total	311.84	351.52	0.00	0.0	11.40	12.27	-0.61	-5.0

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic Aspects

The investment costs for this wedge are based on the investment for a wood chip burner instead of a natural gas burner. General information on the concept of total costs and additional costs as well as fuel costs is provided in chapter 6.1.

Table 6.28 summarises the results: Until 2020 35 million € per year are invested to install biomass furnaces instead of old natural gas burners following the linear diffusion path assumed for this technology wedge. The total cost savings during the operating phase from the substitution of fossil fuels by biomass are 13 million € in the first year; cost savings increase linear to 143 million € in 2020.

Table 6.33: Technology Wedge P-6: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		35	35	35	35	35	35	35	35	35	35	35
Additional Costs		32	32	32	32	32	32	32	32	32	32	32
Operating costs		5	11	16	21	26	32	37	42	47	53	58
Additional Costs		-13	-26	-39	-52	-65	-78	-91	-104	-117	-130	-143

Source: Own calculations.

Operating costs are mainly fuel costs, whereas the increase in maintenance costs is insignificant and also other costs, like costs for the disposal of the ash have an insignificant share. Table 6.29 presents the disaggregation of the investment costs. The only production sector on which the investment costs have a considerable impact is machinery and equipment providing the new biomass furnaces.

Table 6.34: Technology Wedge P-6: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	1.8	0.1	1.8	0.1
Other business services	7.3	0.4	7.3	0.4
Basic metals	3.9	3.1	3.9	3.1
Machinery and equipment n.e.c	87.0	45.2	87.0	45.2
Total	100.0	48.8	100.0	48.8

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

6.2.7 Technology Wedge P-7: Solar thermal energy for process-heat and space heating

In this technology wedge thermal energy on a low temperature level which was formerly produced by natural gas is substituted by solar thermal energy. Table 6.35 shows the characteristics of this wedge.

Table 6.35: Summary Table for Technology Wedge P-7

Solar thermal energy for process-heat and space heating	
Substitution of gas based thermal energy	4.448 PJ of gas based thermal energy substituted by solar thermal energy
Energy service	Production output increases by 23% by 2020
Technology	Solar thermal collectors
Required capacity increase*	3.4 million m^2 collector area until 2020
Diffusion path	Linear
Total investment	1,236 million € by 2020
Operating costs	9 million € in 2020
Additional operating costs	-72 million € in 2020
Emission reduction*	0.245 million t CO_2 in 2020

* Compared to reference scenario.

Solar heat converts solar energy into thermal energy. The basic application involves use of solar energy for space heating or hot water generation. This is accomplished through the absorption of heat into a transport medium flowing within a solar collector. The medium air or a liquid is pumped in a pipe system in a building, heating the space or the water.

The first solar heating plant was built in 1952 in Israel. Since then the worldwide market penetration has been slow but from the 1990s on the solar heating technology has undergone a favourable development. In recent years with increasing instability and uncertainty in energy markets and growing public awareness for environmental protection and mitigation of climate change the interest in renewable energy sources has grown considerably. With these factors the installed collector area has also grown to a total 209.2 million square meters, corresponding to a total heat production capacity of 146.8 GW_{th} worldwide (Weiss, 2007).

The average annual growth rate of solar thermal technology in the period from 1999 to 2007 was around 20% in Europe. This is a very promising Figure and encompassing a period of eight years we can say there is a clear tendency of turning from fossil fuels toward renewable sources of energy. In China and Canada the growth was even higher with 24% and 26% respectively (Weiss, 2007). With this data at hand it is safe to say this is a high potential technology worth further study.

Excluding biomass and hydro power which have been well known for centuries, solar heat is after wind the second biggest source of renewable energy used in the world today. With energy dependency becoming an issue of great importance the potential savings offered by solar heating cannot be ignored. Apart from a chance for economic resource optimisation solar heating systems present a viable solution for domestic energy consumption. The European Union and its member states have committed themselves to achieving a 20% share of renewable energies in Europe's final energy consumption by 2020 and it is clear that solar heat will have to contribute a substantial part of low temperature heat demand.

The EU is second only to China in the number of solar thermal installations and has serious expansion plans for this technology. Given that heat accounts for 49% of final energy demand in Europe (Weiss, 2005) and that only three renewable resources generate heat (biomass, geothermal and solar) internal EU targets and international emissions targets will not be met without a significant contribution from solar thermal system technologies. In order to test the technologies' long term potential detailed surveys were conducted in five representative EU countries studying the technical and economic potential of solar thermal systems. There are three possible scenarios on solar thermal technology deployment (Weiss, 2005) ranging from low to high growth rates of installed capacity (7 – 25% per annum until 2020). A worst case scenario for the solar thermal technology includes moderate energy prices of fossil energy and moderate political support mechanisms. Even within this scenario the growth rate of the technology ranges from 7 to 10%. According to the ESTTP (2008) if there is to be a medium (15 – 20% per annum) or a high growth (25% per annum) of installed capacity political mechanisms are to be implemented or constantly moderate/high rising energy prices of fossil energy would be sufficient.

Austria is one of the countries with the largest collector area installed and is the biggest producer of solar heating systems in Europe. Over the last thirty years enormous experience and knowhow on the production, design and installation of solar heating systems has been gained. This large potential may be applied to other European countries that have a huge solar potential but still need to develop their solar heating market. Spain, Italy and Greece are countries with huge potentials but almost no solar heating installed. Therefore there is a big market in the residential and office building sector, from individual house systems to apartment buildings, where solar heating can be used for hot water and space heating supply. This would contribute positively to Europe's energy independence, mitigation of greenhouse gas emissions and economic opportunities for small and medium enterprises in the sector. Besides residential buildings there exists a large potential for the use of solar heating technologies for heating factory buildings and warehouses. This potential should not be omitted since energy required for heating can account for a considerable share in total energy consumption of a company.

Furthermore in the solar thermal sector a high innovation potential is still available which includes the increase of efficiency and improvement of the storage components etc. which should lead to a reduction of costs. Clearly there is no readymade solution for solar heating systems, rather the system needs to be customised and designed depending on the use of the industrial building, its' thermal efficiency, heat requirements, etc.

From the total amount of energy consumed in Austria low temperature heat (less than 250°C) has a share of 35%. This is a temperature range not considered by the solar heating sector a few years ago. Today there are solar collectors which use diffuse incident light and can harvest sun energy even on cloudy days. This kind of technology is still quite expensive but with material, design and production improvement it is likely that the industrial sector will also cover parts of this temperature range with solar heating technology in the near future. There is a vast amount of research conducted to improve the overall efficiency and cost effectiveness of solar heating: e.g. studying different composite materials as thermal storage media, using coloured glass to improve the architectural integration into buildings while conserving satisfactory energy conversion efficiency, studies on the variation of thermal performance of different solar collectors and solar combi-systems as function of the yearly weather conditions.

In order to assess correctly the feasibility of an integration of solar thermal systems into industrial processes it is necessary to take into consideration the required process temperature rather than the actual temperature of the heat carrier used. In studies like the "POSHIP" study, published in 2001 it has been explored that in many industrial processes high temperature steam is used as a heat carrier, when the temperature required is considerably lower (European Commission Directorate General Energy and Transport, 2001). Such cases are excellent options to integrate solar heat into industrial processes, and also lower the current process energetic requirements. Data obtained by the IEA (Ellehauge, 2003) suggest that more than 50% of the heat requirements in the 1) Food and Tobacco and 2) Mining and Quarrying sectors are below 100 °C. While the same study indicates that the industrial sectors: 1) Machinery and 2) Transport Equipment use temperature heat below 100°C in more than 60%. Normal flat plate collectors are able to provide this energy demand and usually have a reasonable payback time. Depending on the inflation rate fuel prices and the type of fuel they replace, the time required for amortisation ranges from four years (electricity) to seven years (diesel oil).

To date, solar heating has focused almost exclusively on swimming pools and domestic hot water generation and residential space heating. Its use in the commercial and industrial sector is insignificant in comparison, while statistics show that it is exactly this sector that has the biggest energy consumption (30%) within the OECD countries. While one third of this energy is used for electricity production, two thirds are used for heat. A large share of the heat used in the commercial and industrial sector is below 100°C and the majority is below 250°C. The commercial solar collectors on the market can provide heat within this temperature range. With energy dependency becoming an issue of great importance the potential savings offered by solar heating cannot be ignored. Apart from an opportunity for economic resource optimisation, solar heating systems present a viable alternative for space heating of factory buildings and offices.

The European Union and its member states have committed themselves to achieving a 20% share of renewable energy in Europe's final energy demand by 2020 and it is clear that solar heat will have to contribute a substantial share of low temperature heat demand.

Implementation of the energy transition methodology for Technology Wedge P-7

The calculation for the potential of solar energy is based on two applications of solar thermal energy: the use of solar thermal energy for process heat and for solar space heating. To calculate the potential it was split into two different categories: thermal energy up to a level of 100°C and thermal energy up to 250°C. Table 6.36 shows the total contribution of Technology Wedge P-7 to the thermal energy demand of manufacturing. In the year 2020 a potential of 4.4 PJ is achievable.

The calculations for solar thermal process heat applications are based on the study "PROMISE – Produzieren mit Sonnenenergie" assuming that the potential for Austria as estimated in a study published in 2004 (Müller, 2004) will be completely realised in 2020.

The potential of solar space heating is calculated by using two main input parameters, a solar share of 30% and annual growth rate of semi-solar heating systems[32] (every year 1% of space heating demand for the production halls in 2008). The "Design Guidelines – Solar space heating of Factory Buildings" builds the framework for the calculation for semi solar space heating (Jähnig, 2007).

Table 6.36: Technology Wedge P-7: Summary of energy indicators

Solar thermal energy for process-heat and space heating	2008 2008=100	2020 / 2008 %	2020 2008=100
Energy Service (S)			
Energy Service	100	23	123
Energy Intensities			
Useful Energy Intensity (u)	100	0	100
Final Energy Intensity (f)	100	0	100
Final Energy (F)	100	23	123

Energy source	2008 % share in F	2020 / 2008 %	2020 % share in F
Coal	6.4	0.0	6.4
Oil	10.5	0.0	10.5
Gas	33.3	0.0	33.2
Renewables	15.5	0.1	15.6
Electricity	31.6	0.0	31.6
Heat	2.7	0.0	2.7
Total	100.0	0.0	100.0

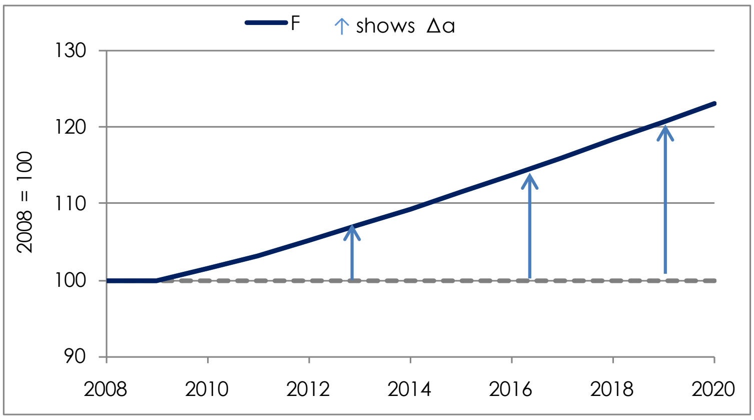
Source: Own calculations.

32 A heating system, which uses solar thermal energy if the solar radiation is high enough, and covers the residual heat demand with another fuel. In our case the backup system is a gas fired burner.

Table 6.36 shows the development of energy indicators according to the EnergyTransition methodology. The relevant energy service is approximated by output which is assumed to grow until 2020 by 23%. Final energy demand increases continuously as a result of the rising energy service.

This wedge replaces thermal energy which is provided by natural gas through solar thermal energy, therefore no changes in the useful energy intensity or the final energy intensity take place. Figure 6.33 shows the development of final energy demand according to the methodology as described in Part B, chapter 3. Due to the rising energy service and constant energy intensities final energy demand increases until 2020 as illustrated by the blue line. The increase in final energy consumption is therefore again equal to the increase in energy service.

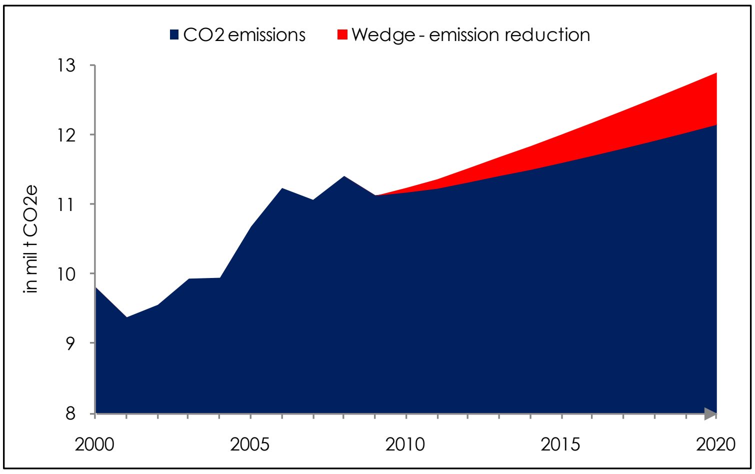
Figure 6.33: Technology Wedge P-7: Effects on final energy[1]



Source: Own illustration. – 1 Δa describes the combined effect of changes in energy services and useful energy intensity. F is final energy consumption.

To make the emission reduction potential visible within the reduction triangle, it is shown compared to the EnergyTransition reference scenario. There exists a potential for increased use of solar energy which translates into a reduction of the demand for fossil fuels as well as CO_2 emissions. Figure 6.34 shows the reduction of CO_2 emissions, which can be achieved through Technology Wedge P-7 in the manufacturing sector. The reduction is achieved by the substitution of natural gas by solar thermal energy.

Figure 6.34: Technology Wedge P-7: Effects on CO_2 emissions



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 6.37 presents the changes in the fuel mix as well as the emission reduction compared to the reference scenario.

Table 6.37: Technology Wedge P-7: Effects on final energy consumption and CO_2 emissions

Energy Source	Final Energy Consumption				CO_2 Emissions			
	2008	2020			2008	2020		
	in PJ		Difference to Reference				Difference to Reference	
		in PJ	in PJ	in %	in mt	in mt	in mt	in %
Coal	19.99	22.30	0.00	0.0	1.99	2.22	0.00	0.0
Oil	32.64	38.45	0.00	0.0	2.41	2.85	0.00	0.0
Gas	103.69	114.26	-4.45	-3.9	5.70	6.28	-0.24	-3.9
Renewables	48.36	55.56	4.45	8.0	1.29	1.53	0.00	0.0
Electricity	98.69	111.26	0.00	0.0	0.00	0.00	0.00	0.0
Heat	8.46	9.69	0.00	0.0	0.00	0.00	0.00	0.0
Total	311.84	351.52	0.00	0.0	11.40	12.88	-0.24	-1.9

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic Aspects

General information for the economic data is provided in chapter 6.1. The compared technologies are solar thermal energy and natural gas based energy because in Technology Wedge P-7 only natural gas is replaced by solar thermal energy.

The investment costs of solar thermal collectors are calculated with the following input parameters:

- 350 kWh/m² provided thermal energy per year
- 350 € per m² installed collector area

Table 6.38 summarises the results: Until 2020 112 million € per year are invested for the installation of solar thermal collectors. The total cost savings during the operating phase from the substitution of gas furnaces by solar thermal panels are 7 million € in the first year; cost savings increase to 72 million € in 2020.

Table 6.38: Technology Wedge P-7: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs		112	112	112	112	112	112	112	112	112	112	112
Additional Costs		111	111	111	111	111	111	111	111	111	111	111
Operating costs		1	2	2	3	4	5	5	6	7	8	9
Additional Costs		-7	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72

Source: Own calculations.

The operating costs of the solar thermal system consist of two categories, electricity and maintenance costs; their share is shown in Table 6.39. All the fuel costs are related to electricity demand of the pumps and control systems but the main part of operating costs is maintenance costs.

Table 6.39: Technology Wedge P-7: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional costs in %
Fuel costs (electricity)	28	100
Maintenance cost	72	0
Total	100	100

Source: Own calculations.

Table 6.40 shows the disaggregation of the investment costs. The production sectors on which the investment costs have a considerable impact are construction work and machinery and equipment. The effects on the construction sector are due to the specific high installation costs for solar thermal systems, whereas the input in the machinery and equipment sector is mainly related to the collector.

Table 6.40: Technology Wedge P-7: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Construction work	58.0	3.0	58.0	3.0
Other business services	2.0	0.0	2.0	0.0
Basic metals	10.0	9.0	10.0	9.0
Machinery and equipment n.e.c	30.0	3.0	30.0	3.0
Total	100.0	15.0	100.0	15.0

Source: Own calculations based on Land Steiermark (2010).

The disaggregation of investment costs is taken from the Styrian Climate Protection Plan (Land Steiermark, 2010).

Cost appraisal

Based on data for the investment and operating phase for the technology wedge P-7 the user costs of capital caused by the investment for the supply with solar thermal energy are calculated. In Table 6.41 the inputs for the cost appraisal as well as the results are shown. For the provision of 1 kWh of solar thermal energy, investment costs are 1 €. This is calculated for a solar gain of 350 kWh/m² collector p.a. A service life of 25 years is assumed.

In order to illustrate the sensitivity of the results with respect to the interest rate, two alternatives are calculated, alternative A with an assumed real interest rate of 5% and B with an interest rate of 2.5%. With an interest rate of 5%, the user costs of capital are 0.09 €/kWh p.a., this results in total costs of 0.096 €/kWh p.a. For Alternative B the user costs of capital are 0.065 €/kWh p.a. All of the costs are additional, because the difference (reference system compared to the new system) for one kWh of thermal energy, concerning investment costs is negligible. To make the sensitivity visible, the price for district heat is also shown in Table 6.41

Table 6.41: Cost appraisal solar thermal collector system with alternative interest rates

Solar thermal		**2010**	**2020**
Unit Activity	1m²		
Investments			
Service life	years	25	25
Interest rate	% p.a.	5.0	2.5
Investment price	€/m2	350.00	350.00
Investment price	€/kWh	1.00	1.00
User cost of capital	***€/kWh p.a.***	***0.09***	***0.07***
Operating			
Solar gain	kWh/m2 p.a.	350.00	350.00
Energy demand	kWh	0.01	0.01
Mainetance costs	in %	0.01	0.01
Energy price (eletricity)	€/MWh	110.00	110.00
Operating costs	***€/kWh p.a.***	***0.01***	***0.01***
Total			
Total costs solar	*€/kWh p.a.*	*0.10*	*0.07*
Heat price	*€/kWh p.a.*	*0.08*	*0.08*
Additional costs	***€/kWh p.a.***	***0.10***	***0.07***

Source: Own calculations.

6.2.8 Combination of Technology Wedges

Most technology wedges have impacts on the potential of other technology wedges. Therefore a sequence must be set up for their combination to ensure that all the effects on the changed potential of the subsequent wedges are taken into account. For the manufacturing sector the technology wedges were already ranked in this order throughout the whole work package:

- Technology Wedge P-1 Energy demand of production halls
- Technology Wedge P-2 Process intensification and process integration
- Technology Wedge P-3 Energy efficient engines
- Technology Wedge P-4 Combined heat and power
- Technology Wedge P-5 Substitution of fossil energy sources with high emission-coefficients
- Technology Wedge P-6 Biomass for process-heat
- Technology Wedge P-7 Solar thermal energy for process-heat and space heating

In the following the interdependencies between the technology wedges are described. The efficiency wedges P-1 to P-4 influence the qualitative and quantitative mixture of the energy demand in the manufacturing sector, therefore efficiency measures should always be done first. The technology wedges P-1 and P-2 do not affect each other because their potential is located in different useful energy categories. But Technology Wedge P-3 has a lower potential because the demand of the engines is already reduced through P-2.

Also P-4 as well as P-5 is influenced by the savings of fossil fuels in P-1, P-2 and P-3. Technology Wedge P-6; the substitution of biomass, is affected by the result of P-5 because oil and coal have already been partly substituted. The potential of Technology Wedge P-7 is not influenced by the other measures. The potential for semi-solar space-heating is calculated with regard to the results of lower energy demand in P-1 but the potential for solar thermal process heat is still available in the full amount after all the reductions and substitutions. Table 6.42 presents the results of the combination of Technology Wedge P-1 up to P-7.

Table 6.42: Changes in final energy demand for wedge combination in 2020 compared to reference scenario

Technology wedge		Final Energy consumption 2020 Difference to Reference in PJ						
		Coal	Oil	Gas	Renewables	Electricity	Heat	Total
P-1	Energy demand of production halls	-0.01	-1.39	-2.49	-0.51	-2.27	-1.11	-7.78
P-2	Process Intensification and Process Integration	-2.41	-5.63	-14.85	-8.34	-6.72	-0.43	-38.38
P-3	Energy efficient engines	0.00	-0.63	0.00	0.00	-8.08	0.00	-8.71
P-4	Combined Heat and Power				not applicable			
P-5	Substitution of fossil energy sources with high emission-coefficients	-8.79	-6.05	13.92	0.00	0.00	0.00	-0.93
P-6	Biomass for process-heat	0.00	0.00	-9.43	9.43	0.00	0.00	0.00
P-7	Solar thermal energy for process-heat and space heating	0.00	0.00	-4.45	4.45	0.05	0.00	0.05
	Total	-11.21	-13.70	-13.65	5.02	-19.93	-1.54	-55.01

Source: Statistics Austria (2009a, b); own calculations.

Based on the changes of the energy demand of the technology wedge combination, the CO_2 emissions were calculated. Table 6.43 shows the reduction of CO_2 emissions which is achieved by the technology wedges P-1 up to P-7.

Table 6.43: Changes CO_2 emissions for wedge combination in 2020 compared to reference scenario

Technology wedge		CO_2 Emissions 2020 Difference to Reference in mt						
		Coal	Oil	Gas	Renewables	Electricity	Heat	Total
P-1	Energy demand of production halls	0.00	-0.11	-0.14	0.00	0.00	0.00	-0.25
P-2	Process Intensification and Process Integration	-0.23	-0.44	-0.82	0.00	0.00	0.00	-1.48
P-3	Energy efficient engines	0.00	-0.05	0.00	0.00	0.00	0.00	-0.05
P-4	Combined Heat and Power	not applicable						
P-5	Substitution of fossil energy sources with high emission-coefficients	-0.83	-0.47	0.77	0.00	0.00	0.00	-0.53
P-6	Biomass for process-heat	0.00	0.00	-0.52	0.00	0.00	0.00	-0.52
P-7	Solar thermal energy for process-heat and space heating	0.00	0.00	-0.24	0.00	0.00	0.00	-0.24
	Total	-1.05	-1.07	-0.75	0.00	0.00	0.00	-2.87

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

7 Technology wedges for electricity and heat supply

7.1 Introduction

In the following the catalogue of technology wedges developed for electricity and heat supply within WP 4 is presented. A technology wedge originates from the comparison of a reference path with respect to electricity and heat supply and a deliberately chosen different technological path. The method of calculating the reference scenario is extensively discussed and described in Part B, chapter 2. Therefore here only a summary of parameters that are the reference points for technology wedges for electricity and heat supply is outlined.

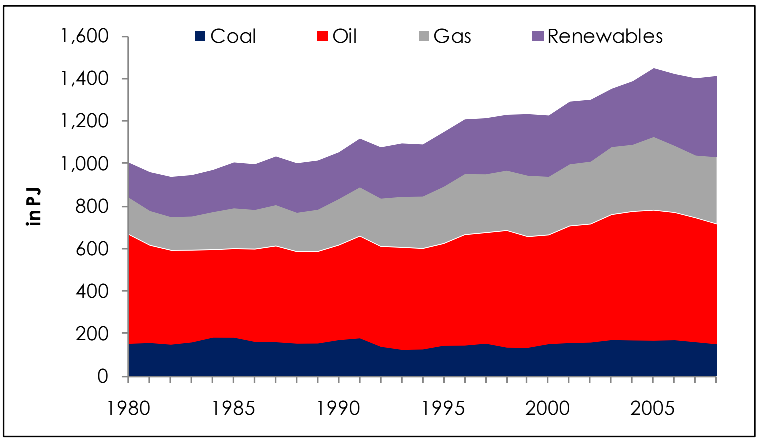
Facts, data and status quo

Electricity and heat demand and hence transformation output from energy generation plants have been constantly rising in Austria. Fossil fuels still account for a large part in Austrian energy generation.

Figure 7.1 shows the development of primary supply of coal, oil and gas for all uses. Between 1980 and 2008 primary energy supply increased by 44% from 991 PJ to 1,428 PJ. With a share of 39% (563 PJ), oil products were the largest category in primary energy supply in 2008. The share of gas in primary energy supply was 22%; renewables and coal accounted for 27% and 11% of respectively. Since 1980 the primary supply of oil products has increased by 10%. Both the high share and the sharp increase are mainly due to the high and rising energy demand in the transport sector. Mainly because of a sharp increase of biomass primary supply of renewables more than doubled between 1980 and 2008. Primary supply of gas increased by 80% between 1980 and 2008 while that of coal stayed more or less stable (154 PJ to 152 PJ) over this period.

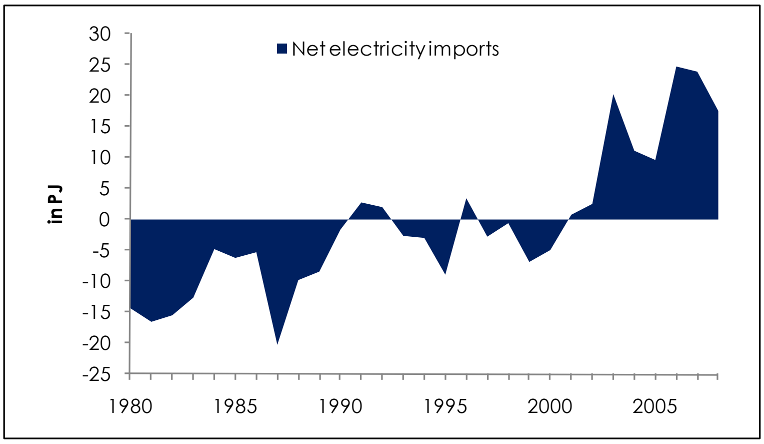
Data on energy supply reveals another insight on the Austrian energy system. While Austria was a net exporter of electricity before and throughout most of the 1990s (see Figure 7.2), since 2001 Austria has become a net importer of electricity. This is mainly due to a pronounced increase in electricity consumption.

Figure 7.1: Development of primary energy supply



Source: Statistics Austria (2009a).

Figure 7.2: Development of electricity net imports

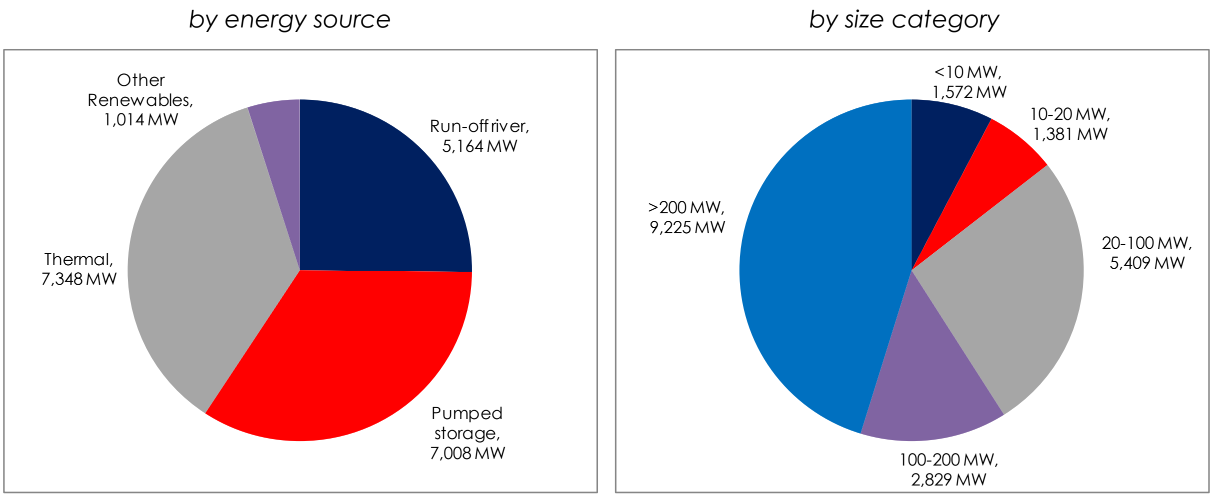


Source: Statistics Austria (2009a).

Figure 7.3 illustrates Austrian electricity generation capacities in 2008 by energy source and plant size. Hydropower accounts for 59% (12.2 GW) of Austrian plant capacity in 2008. The shares of thermal power and other renewables (except hydropower) are 35% (7.3 GW) and 5% (1.0 GW) respectively. While only 8% (1.6 GW) accrue to plants with a capacity below 10 MW, 49% (9.2 GW) accrue to plants with a capacity higher than 200 MW.

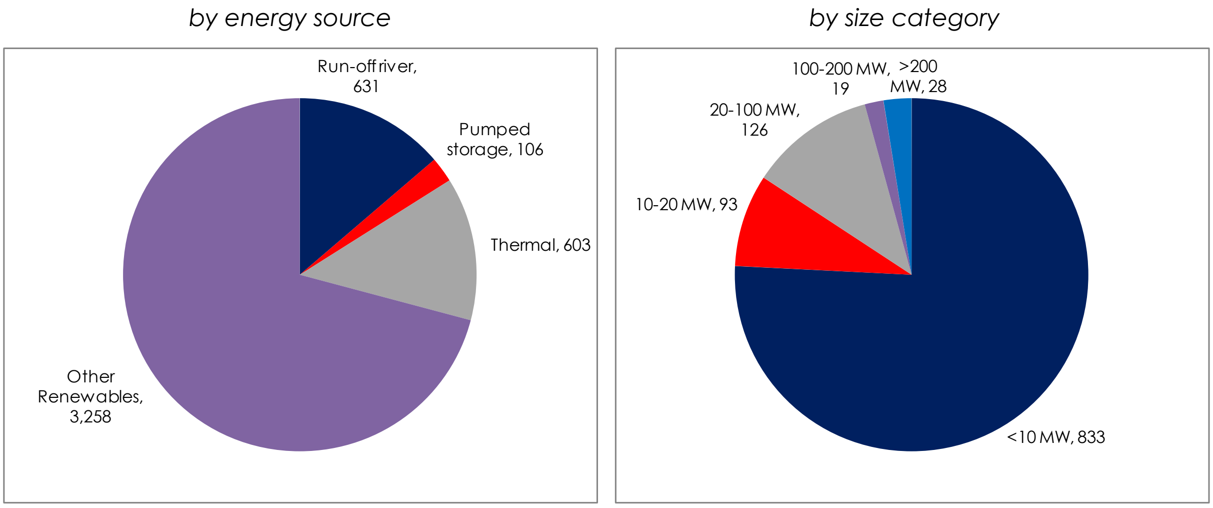
Figure 7.4 shows the number of Austrian electricity generation plants in 2008 by energy source and size. Most electricity generation plants are other renewables (51%) followed by hydropower (12%) and thermal power (9%). Together with Figure 7.3 this highlights that thermal plants have on average the largest plant capacity (12 MW) while the average capacity of other renewable plants is only 0.3 MW. More than 95% (more than 6,000 electricity generation plants) have a capacity below 10 MW. The 28 largest electricity plants have a capacity of more than 200 MW each.

Figure 7.3: Electricity generation capacity 2008 in MW



Source: E-control (2009b).

Figure 7.4: Number of electricity generation plants in 2008

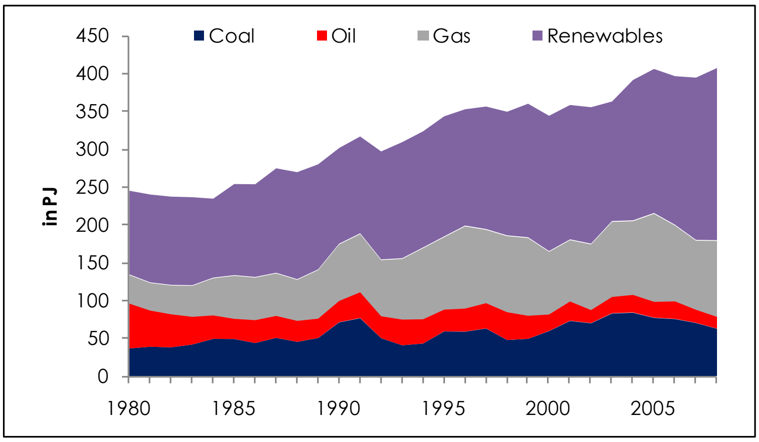


Source: E-control (2009b).

Figure 7.5 shows the development of transformation input in electricity and heat generation plants by fuel type. Between 1980 and 2008 total transformation input in energy generation plants has increased by 66% from 245 PJ to 406 PJ. Renewables (including hydropower) are the dominant energy source in electricity generation. Total transformation input of renewable energy sources increased from 110 PJ in 1990 to 227 PJ in 2008. Transformation input in coal, oil and gas plants rose from 134 PJ in 1980 to 180 PJ in 2008.

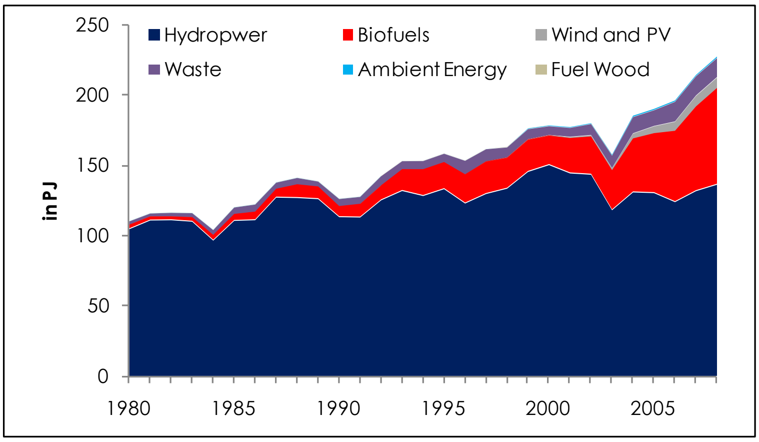
Figure 7.6 illustrates transformation input based on renewables by energy source. With a transformation input of 137 PJ in 2008 hydropower still dominates (renewable) power generation, but in recent years shows no increments. Fluctuations in hydro based electricity mainly reflect changes in hydrolicity: In 2000 a maximum in hydro-generation due to high hydrolicity was observed; the trough in 2003 reflects droughts and low water conditions due to a heat wave. Biomass-based energy generation has steadily increased from 3 PJ to 69 PJ between 1980 and 2008 and drives growth in renewable energy generation in the last years. Other renewable energy sources only account for a small share in power generation.

Figure 7.5: Development of transformation input



Source: Statistics Austria (2009a).

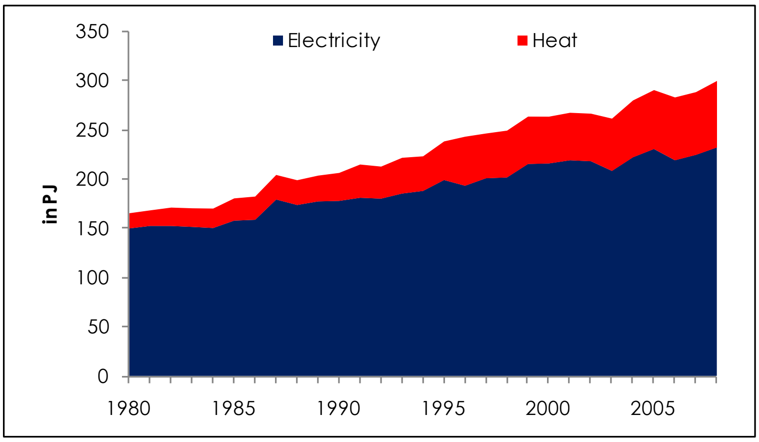
Figure 7.6: Development of transformation input (renewables)



Source: Statistics Austria (2009a).

In Figure 7.7 the development of transformation output between 1980 and 2008 is illustrated. Electricity output increased from 150 PJ in 1980 by 55% to 232 PJ in 2008. In this period electricity output from renewable energy sources (mainly hydropower and biomass) increased from 80 PJ to 162 PJ. Electricity output from fossil fuels rose from 43 PJ in 1980 to 69 PJ in 2008. The shares of fossil and renewable energy sources in electricity output hence stayed roughly constant. Heat output rose from 15 PJ to 68 PJ between 1980 and 2008. In 2008 approximately two thirds of heat output accrued from renewable energy sources.

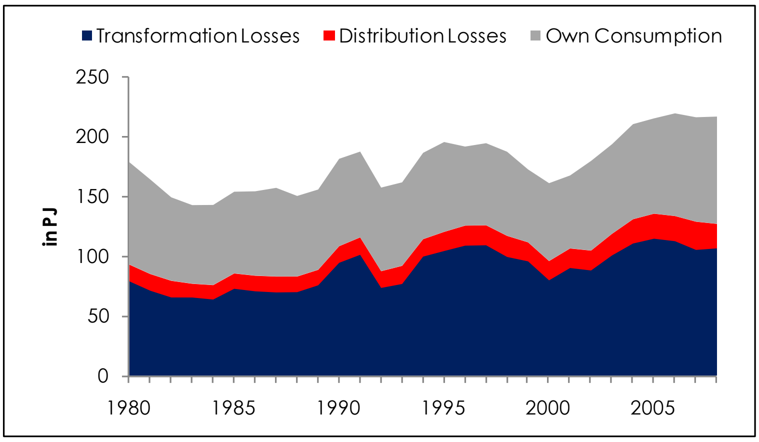
Figure 7.7: Development of transformation output



Source: Statistics Austria (2009a).

Figure 7.8 shows the development of losses in electricity and heat generation and distribution. Total losses and own consumption of the energy sector increased from 179 PJ to 217 PJ between 1980 and 2008. However, the share of losses in transformation input declined which indicates efficiency improvements in energy generation[33]. Transformation losses accounted for 80 PJ in 1980 and increased to 107 PJ by 2008. Distribution losses and own consumption were 14 PJ in 1980 and increased to 20 PJ by 2008. Own consumption increased slightly from 85 PJ to 89 PJ between 1980 and 2008.

Figure 7.8: Development of transformation and distribution losses and own consumption of the energy sector



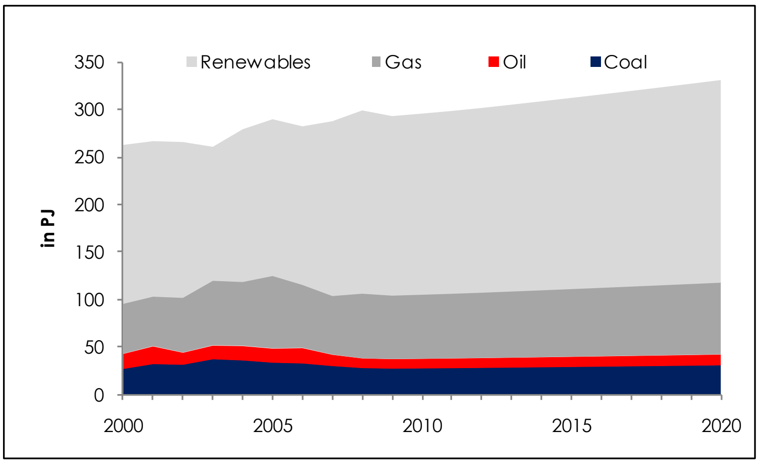
Source: Statistics Austria (2009a).

[33] Transformation losses are defined as the difference between transformation input and transformation output. The Austrian Energy Balances report for hydropower, wind, photovoltaics and ambient heat efficiency of 100% which means no transformation losses for these technologies are taken into account.

Reference scenario for electricity and heat supply

The primary goal of the work package "Electricity and heat supply" is to develop technology wedges that achieve significant emission reductions in the energy sector. In order to quantify the emission reduction effect of specific technology wedges one needs a view of a possible development of energy supply structures until 2020 and a broad picture until 2050, a so called reference scenario. The reference scenario extrapolates the historical trends until 2020 based on GDP growth and assumed development of sectoral production indices. According to this scenario increasing demand for heat and electricity is estimated (see Part B, chapter 2) which consequently requires an increase in transformation output. The reference scenario hence assumes energy output from fossil fuels to rise until 2020 by a total of 11% (12 PJ) compared to 2008. Transformation output from renewables is also expected to grow by 11% (20 PJ) by 2020 (see Figure 7.9).

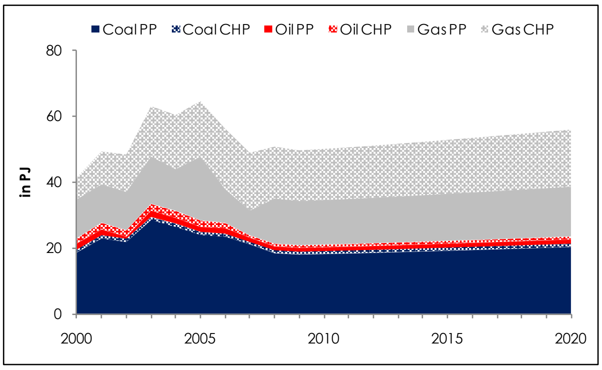
Figure 7.9: Transformation output (electricity and heat) by energy source – reference scenario

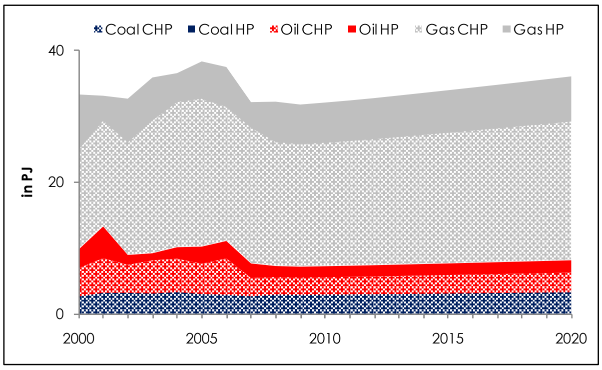


Source: Statistics Austria (2009a, b); own calculations.

Figure 7.10 shows the development of electricity and heat output from fossil fuel based public plants as calculated in the reference scenario. Overall, electricity production is presumed to increase by 10% from 51 PJ in 2008 to 56 PJ in 2020. In this scenario, projected electricity output from fossil fuels is below 2003 to 2006 levels. Electricity generation from coal and oil plants is estimated to stay constant until 2020. Gas based electricity generation is expected to increase both from power plants and from CHP plants. A growth in heat production is also estimated in the reference scenario. Heat production from coal and oil based plants is assumed to slightly increase by 2020 compared to 2008. For gas based heat generation a rather pronounced increase – mainly from CHP plants – is expected (see Figure 7.10).

Figure 7.10: Electricity output (left) and heat output (right) of public plants – reference scenario





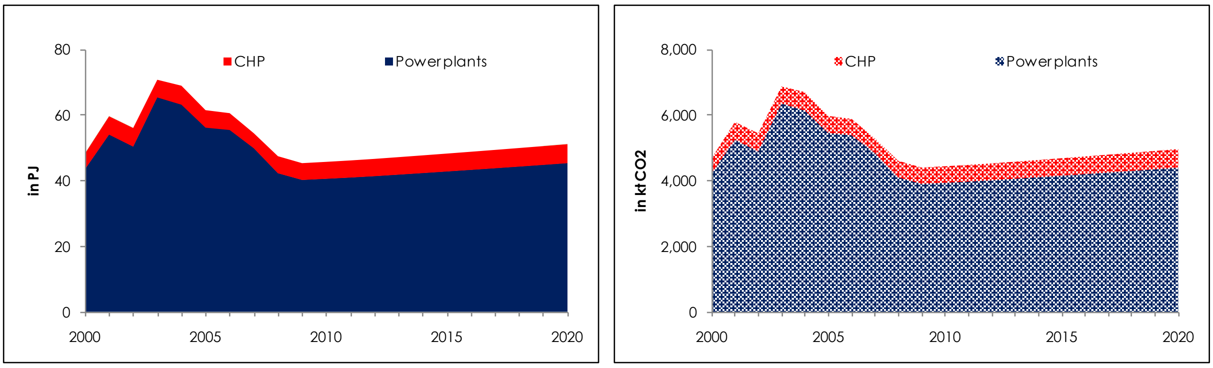
Source: Statistics Austria (2009a, b); own calculations.

Figures 7.11 to 7.13 illustrate transformation input and CO_2 emissions associated with the projected energy output in the reference scenario.

In 2008 coal input in power and CHP plants was 47 PJ. In the reference scenario coal input is estimated to rise to 51 PJ by 2020[34]. Related CO_2 emissions hence are calculated to rise from 4.6 million t in 2008 to 5.0 million t by 2020 of which 89% are emitted from power plants and 11% from CHP plants (see Figure 7.11). CO_2 emissions from oil based plants increase from 0.7 million t in 2008 to 0.8 million t in 2020. CHPs account for the largest share in oil input and hence emissions from oil based energy generation. Gas represents the most important energy source for transformation output of public plants. In 2008 80 PJ gas were used in energy generation plants of which the largest part accrued to CHP plants. Due to rising energy demand in the reference scenario gas input is expected to increase to 89 PJ in 2020. Related CO_2 emissions are estimated to increase from 4.4 million t in 2008 to 4.9 million t in 2020. 2.7 million t CO_2 are emitted by CHPs, 1.7 million t by power plants and the remaining 0.5 million t by heat plants (Figure 7.13).

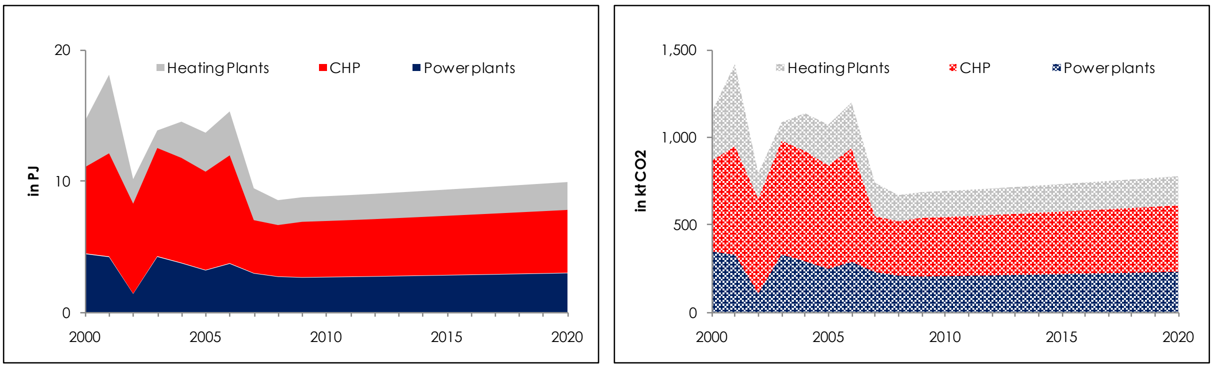
[34] Despite an increase in transformation input of all fossil fuels, their shares slightly shift until 2020. The share of coal in total transformation input in public plants decreases from 34.8% in 2008 to 34.0% in 2020. The share of oil slightly increases to 6.6% compared to 6.3% 2008 whereas the share of gas increases from 58.9% to 59.4%.

Figure 7.11: Coal input in public plants (left) and related CO_2 emissions (right) – reference scenario



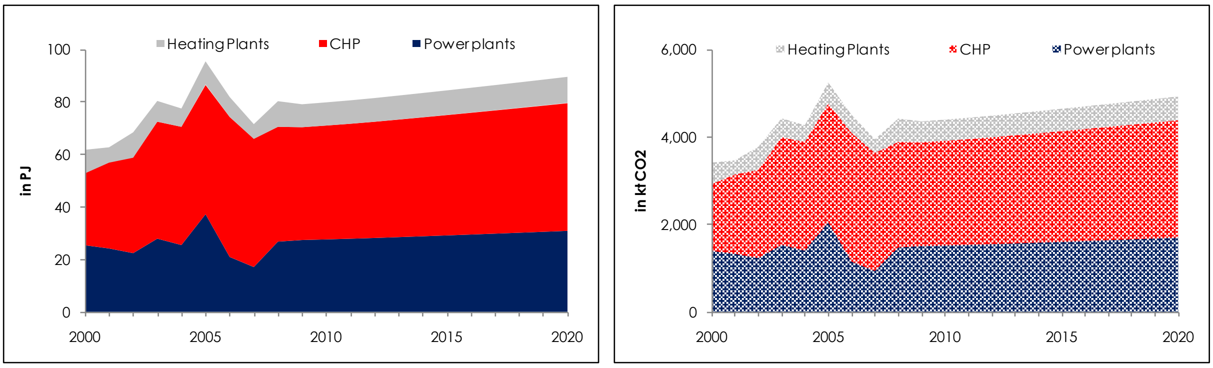
Source: Statistics Austria (2009a, b), UNFCCC(2010); own calculations.

Figure 7.12: Oil input in public plants (left) and related CO_2 emissions (right) – reference scenario



Source: Statistics Austria (2009a, b), UNFCCC(2010); own calculations.

Figure 7.13: Gas input in public plants (left) and related CO_2 emissions (right) – reference scenario



Source: Statistics Austria (2009a, b), UNFCCC(2010); own calculations.

The reference scenario calculated for EnergyTransition sets the boundaries for a feasible development and thus for the maximum emission reduction potential that can be achieved in the energy sector by 2020. I.e. about 4 million t CO_2 from existing coal based power plants, 1.5 million t CO_2 from existing gas power plants and 0.5 million t CO_2 from existing heat plants are assumed as the technical potentials for CO_2-reduction. In addition, 3.2 million t CO_2 from existing CHPs (although these plants show high efficiency) as well as 0.9 million t CO_2 from new plants could be reduced theoretically.

Emission reduction potentials in the energy sector generally include a shift to renewables or fossil fuels with lower emission factors as well as efficiency improvements[35], e.g. by the employment of co-generation plants instead of stand-alone technologies (see e.g. Öko-Institut – Prognos, 2009; Pacala – Socolow, 2004). Based on their technical potential in Austria the following technology wedges will be analysed until 2020 and a qualitative outlook until 2050 will be given:

- a substitution of fossil electricity generation by wind power;
- a substitution of fossil electricity generation by run-of-river plants;
- a substitution of coal based electricity generation and gas based heat generation by biomass and biogas based CHPs.

Substitution refers to existing fossil based energy generation plants. The assumption of the substitution of (Austrian) fossil based energy generation is a technical one. Electricity generation from renewables as considered in the technology wedges could also substitute electricity imports. Furthermore the mix of electricity generation substituted could differ from the options chosen in EnergyTransition. In addition to the above listed technology wedges one technology wedge illustrates the effects resulting from changes in electricity and heat demand in the areas mobility, buildings and industry.

In the next section the different technology wedges for electricity and heat supply are described in detail. Each technology wedge is based on a detailed storyline discussing the core assumptions that determine emission reductions, such as technological parameters (efficiency factors, full load hours, etc.) and cost parameters (investment costs, operating costs). For selected technologies a cost appraisal (cost comparison method) is conducted yielding average costs per kWh electricity generation.

7.2 Storylines for technology wedges for electricity and heat supply

7.2.1 Technology Wedge E-1: Substitution of fossil electricity generation by wind power

This technology wedge analyses a substitution of electricity from existing coal and gas fired power plants by wind power. The characteristics of the wedge are summarised in Table 7.1.

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35 Evidence on the technical potential for various technologies is taken from the literature, e.g. from ÖROK (2009) for wind power.

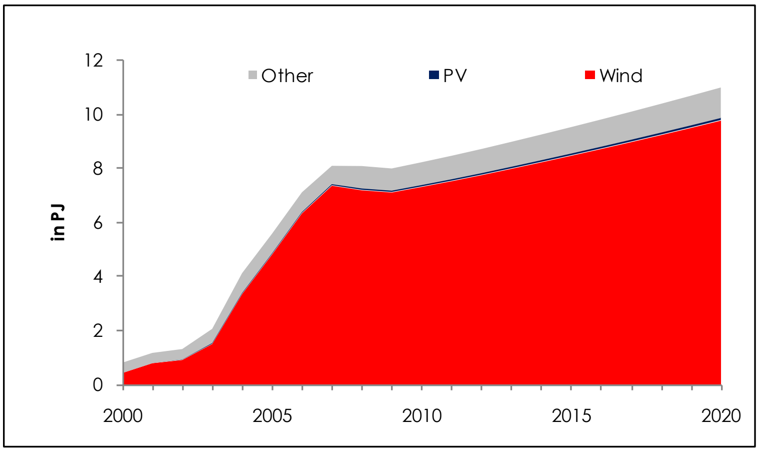
Table 7.1: Summary Table for Technology Wedge E-1

Substitution of fossil electricity generation by wind power	
Substitution of fossil electricity	2.5 PJ of coal and 3.3 PJ of gas based electricity generation substituted by wind
Technology	Wind turbine with 2 MW capacity
Required capacity increase*	728 MW (364 wind turbines)
Diffusion path	Linear
Total investment	965 million € by 2020
Operating costs	25 million € in 2020 (69.000 € p.a. per wind turbine)
Emission reduction by wedge*	1million t CO_2 in 2020

* Compared to the reference scenario.

Wind power features a very short history in Austria with the first wind turbines being installed in the mid 1990s. Since then wind power experienced high growth rates, but still accounts only for a small share in Austrian electricity generation[36]. In 2008 wind power contributed 7.2 PJ (3%) to Austrian electricity generation. Up to 2020 the feasible electricity generation potential from wind is estimated in the range of 16 PJ to 26 PJ[37] (ÖROK, 2009). In the reference scenario wind power is estimated to increase to 10 PJ which leaves an unused potential of 6 to 16 PJ.

Figure 7.14: Development of transformation output from new renewables – reference scenario



Source: Statistics Austria (2009a, b) and Eurostat; own calculations.

The technology wedge explores the substitution of coal and gas fired electricity generation in existing power plants by wind power given the estimates for wind power potential in Austria.

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[36] Between 1995 and 2007 wind power in Austria grew on average by 89% p.a. which is clearly above the EU average of 31%. Overall electricity generation from windmills contributes only a small share to Austrian electricity generation (3%).

[37] See e.g. WIFO, Wegener Center and EEG (2007) and the literature cited therein. Kaltschmitt et al. (2009), however, estimate the technical supply potential of wind power 64,8 PJ.

The underlying storyline thus assumes a replacement of electricity generation from existing coal and gas power plants of energy producing companies by an intensified use of wind power yielding a reduction in CO_2 emissions.

The following assumptions are made: Only a replacement of existing coal and gas power plants is analysed. The Austrian energy balance gives an energy efficiency factor[38] of 43% for coal power plants and an efficiency factor of 51% for gas power plants for the year 2008. It is assumed that the efficiency factor of the existing power plants remains constant until 2020.

Implementation of EnergyTransition methodology for technology wedge E1

In the project EnergyTransition all technology wedges are developed according to a common framework as presented in Part B, chapter 2 to ensure their comparability. Technology wedges for electricity and heat supply are modelled using the variables transformation output (TO), transformation efficiency (e) and transformation input (TI).

Table 7.2 and Figure 7.15 summarise the change in the variables for Technology Wedge E-1: For the wedge we assume that total electricity output remains constant, but a substitution of electricity from fossil power plants by wind power occurs. Transformation output of coal and gas power plants decreases by 18% while wind transformation output increases by 80% compared to 2008. It has to be stressed that this is a technical assumption as a different mix of electricity generation substituted could be chosen as well as a change in electricity imports. It is assumed that transformation efficiency remains constant for the different technologies. This results in a decrease in transformation input from coal and gas power plants by 18% while wind transformation input increases by 80% which yields a reduction in overall transformation input of 2% (Δt).

Table 7.2: Technology Wedge E-1: Summary of energy indicators

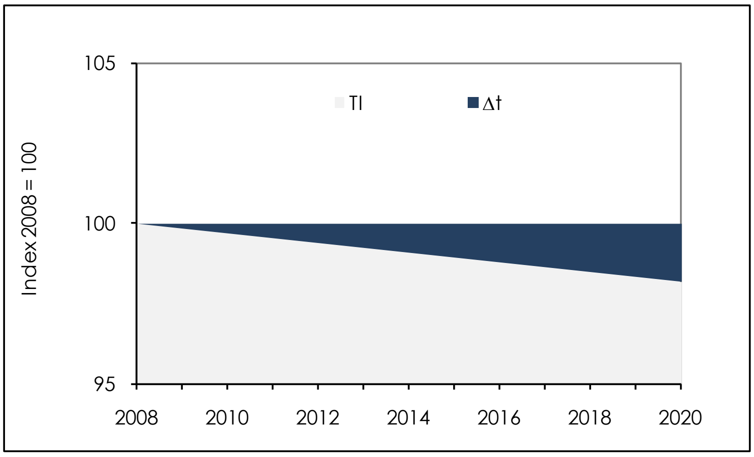
Substituting Single Coal and Gas Electricity Generation by Wind - linear diffusion	**2008** 2008=100	**2020/2008** %	**2020** 2008=100
Transformation Output (TO)	**100**	**0**	**100**
Coal	100	-18	82
Gas	100	-18	82
Wind	100	80	180
Transformation Input (TI)	**100**	**-2**	**98**
Coal	100	-18	82
Gas	100	-18	82
Wind	100	80	180

Source: Statistics Austria (2009a), Eurostat, UNFCCC (2010); own calculations.

[38] The efficiency factor gives the ratio of transformation output to transformation input in percent.

Figure 7.15 illustrates the changes in transformation input over time compared to 2008. These values can then be transformed into absolute changes compared to 2008 but also compared to the reference scenario. Using emission factors by energy source one can then calculate absolute changes in CO_2 emissions resulting from this technology wedge.

Figure 7.15: Technology Wedge E-1: Effects on transformation input[1]



Source: Statistics Austria (2009a), Eurostat, UNFCCC (2010); own calculations. – [1] Δt describes the effect of changes in transformation efficiency on transformation input. TI is transformation input.

The wind turbines considered in Technology Wedge E-1 each have a capacity of 2 MW. This represents the average standard size of existing and currently planned wind turbines in Austria. Per year on average 2,200 full load hours are assumed[39]. With respect to future technology development an increase in wind turbine capacity is expected. Haas et al. (2008) e.g. assume 5 MW as standard capacity for new wind turbines in 2050 that requires an increase in wind turbine height to 120 m. Due to the higher tower wind speeds increase on average by 0.2% and wind turbines therefore show 0.4% higher wind earnings per capacity compared to existing wind turbines. A different strand of development might come from micro wind turbines for buildings etc. One could imagine that sites such as cell towers, mobile phone base stations or pylons could be used as location for micro wind turbines. Micro wind turbines are not considered as technological option for the power sector as (currently) system specific investment costs are 4 to 5 times higher than for conventional wind turbines. Furthermore, wind earnings per rotor area are 10% to 50% lower (see e.g. Haas et al., 2008) compared to conventional wind turbines.

[39] 2,200 full load hours p.a. as assumed by IG Windkraft are based on e-control specification (IG Windkraft, 2010) and are rather conservative estimates: Kaltschmitt et al. (2009) use full load hours in the range of 2,120 to 2,820 for 2 MW windmills. IG Windkraft uses full load hours in the range of 1,600 to 2,400 p.a. If full load hours are calculated based on total transformation output per year from windmills and windmill capacities at the end of the year (e-control, 2009a, b), in 2008 1,900 full load hours are obtained.

Electricity generated from wind power can show high fluctuations over time, on an hourly, daily and seasonal basis. Annual fluctuations may also occur but on a lower level. For the technology wedge we assume rather conservative full load hours, so annual fluctuations are of minor concern here. Because of fluctuations wind power requires backup systems that can provide electricity in case of wind power shortfall. A broad range of technologies can in principle be used as backup systems for wind power, including biomass, combinations with other renewables, fossil-run backup systems, pumped storage hydroelectricity or electricity imports. Research by ISI even suggests transforming excessive wind power into methane for storage (Fraunhofer Gesellschaft, 2010). The question of energy storage technologies is one of the top research questions, currently in the context of increasing the share of intermittent renewable energy sources in electricity generation.

Each of the options mentioned has specific advantages and disadvantages: Local biomass supply is limited[40] and can be used for different purposes (electricity generation, biofuels in transport, heating systems in buildings, material use etc.). In order to increase efficiency in energy generation biomass should only be used in cogeneration (in the energy sector). This would then, however, have feedbacks to other areas of the energy system as additional heat is generated. Importing electricity would be an alternative that is more or less immediately available without additional investment costs, but would further increase Austria's energy dependency and is excluded in the system boundary of this analysis. A combination of wind power with other "new" renewables, e.g. photovoltaics, might probably be insufficient as a back-up system as solar power is also an intermittent energy source. In the literature (e.g. Auer et al., 2006) the use of natural gas as a backup system is often assumed given that gas plants can provide balance energy quickly at relatively low costs compared to other backup technologies. The use of fossil fuels is, however, problematic as these entail CO_2 emissions and hence contradict the aim of emission reductions in a transition to a low carbon energy system. Pumped-storage hydropower is also widely assumed as a backup system for wind power and other renewables (e.g. Öko-Institut – Prognos, 2009). Pumped-storage hydroelectricity generation exhibits efficiency factors of at most 75% to 85% for highly efficient new plants. This means that the plant uses more electricity for pumping up the water than it finally produces. In addition the construction of pumped-storage hydroelectricity plants impacts the environment. Despite these concerns pumped-storage electricity generation generally provides a stable zero-carbon backup system although at the moment at higher costs than fossil backup systems.

As in Öko-Institut and Prognos (2009), for the technology wedge considered here the option of pumped-storage hydroelectricity generation that uses excessive electricity generation by wind turbines as a backup system is assumed. For the economic evaluation of the investment

[40] Large scale biomass imports for energy production are not considered as that would further increase Austria's energy dependency and would be connected with negative aspects for the environment due to longer shipping distances.

and operating phase the system boundary nevertheless only covers the installation and operation of wind turbines.

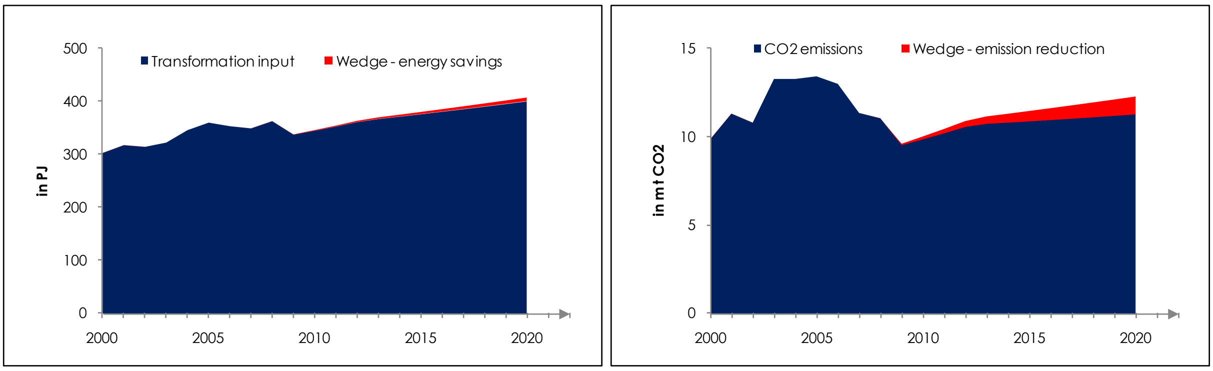
Assuming a reduction of CO_2 emissions of 1 million t by 2020 through this technology wedge compared to emissions in the reference scenario requires that 3.3 PJ electricity from coal power plants and 2.5 PJ from gas power plants are substituted by wind power. This implies that additional 728 MW of wind power (364 2-MW-wind turbines) have to be installed by 2020 compared to the reference scenario. This can basically be achieved by different diffusion paths of the new wind power capacities (linear, exponential, step function).

In this wedge a linear diffusion of additional wind power starting in 2009 is assumed as no significant changes in cost structures are expected by 2020 (see e.g. Haas et al., 2008): Each year 30 MW of additional wind power capacity are installed producing 480 TJ electricity. This requires additional annual investments in the range of 80 million € (Ecofys et al., forthcoming). In 2020 5.8 PJ of additional wind power is generated by the new wind turbines assuming 2,200 full load hours. Electricity output from coal power plants in return is reduced by 3.3 PJ and electricity output from gas power plants by 2.5 PJ respectively. Coal and gas input in these plants hence is reduced in 2020 by 7.6 PJ and 4.8 PJ respectively[41] compared to the reference scenario.

According to the emission factor of 97 t CO_2/TJ for coal and 55 t CO_2/TJ for gas (UNFCCC) this reduction in transformation input is equivalent to a reduction of 1 million t CO_2 by 2020. 0.7 million t CO_2 are reduced by the substitution of electricity generation in coal power plants by wind turbines and 0.3 million t CO_2 are reduced by the substitution of gas. Over the whole period 2008-2020 this wedge reduces 7 million t CO_2 compared to the reference scenario (see Figure 7.16).

Table 7.3 summarises the effects of the implementation of Technology Wedge E-1 on transformation input and related CO_2 emissions.

Figure 7.16: Technology Wedge E-1: Effects on transformation input (left) and CO_2 emissions (right) in energy generation



Source: Statistics Austria (2009a, b), Eurostat, UNFCCC (2010); own calculations.

[41] This transformation input reflects the efficiency factors of 43% and 51% derived from the Austrian energy balances.

Table 7.3: Technology Wedge E-1: Effects on transformation input and related CO_2 emissions

Energy source	Transformation input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Fossil Fuels	**136,34**	**139,54**	**-12,41**	**-8,2**	**9,69**	**9,76**	**-1,00**	**-9,3**
Coal	47,48	44,09	-7,60	-14,7	4,61	4,28	-0,74	-14,7
Oil	8,58	10,04	0,00	0,0	0,67	0,78	0,00	0,0
Gas	80,28	85,41	-4,82	-5,3	4,42	4,70	-0,26	-5,3
Renewables	**226,83**	**260,60**	**5,77**	**2,3**	**1,34**	**1,50**	**0,00**	**0,0**
Wastes	13,38	15,01	0,00	0,0	1,34	1,50	0,00	0,0
Biofuels	68,76	78,48	0,00	0,0	0,00	0,00	0,00	
Hydro	136,60	150,24	0,00	0,0	0,00	0,00	0,00	
Wind	7,19	15,63	5,77	58,5	0,00	0,00	0,00	
PV	0,07	0,10	0,00	0,0	0,00	0,00	0,00	
Other	0,83	1,14	0,00	0,0	0,00	0,00	0,00	
Total	**363,17**	**400,14**	**-6,65**	**-1,6**	**11,03**	**11,26**	**-1,00**	**-8,2**

Source: Own calculations.

As the overall potential of wind power in Austria is estimated in the range of 16 to 26 PJ (see above) and wind based electricity accounts for 10 PJ in the reference scenario a technology wedge of this type can be implemented several times by 2020.

Economic aspects

Investment and operating costs of wind turbines that are the input parameters for the input output analysis in Part B, chapter 9 and the cost appraisal are presented in Tables 7.4 to 7.6. The data for both, the investment and operating costs, are based on Ecofys et al. (forthcoming) and IG Windkraft (2009). For coal and gas power plants as reference technologies we use data provided by RENERGIE (2009). For the analysis all costs are held constant until 2020. This also applies to the fuel costs which, however, can be expected to increase significantly until 2020, especially for fossil fuels (e.g. due to the scarcity of the energy sources or due to environmental regulation for CO_2 emissions such as emissions trading or a carbon tax). The assumption of constant energy prices directly influences the effect on additional operating costs which would show a higher negative size with increasing prices for fossil fuels.

From the information compiled we assume investment costs of 2.65 million € for each windmill. Based on the assumption that starting in 2009 each year 30 additional windmills are installed in this wedge total investment costs amount to 964.5 million € by 2020 (80.3 million € p.a.) using cost data from Ecofys et al. (forthcoming). The largest share in investment costs is related to the wind turbine followed by construction and transport activities (IG Windkraft, 2009). Due to this cost structure the sectors electrical machinery and apparatus, construction work, transport and other business services are most strongly affected by the investment. Moderate investment effects, however, also apply to the sectors machinery and equipment and precision instruments. It is assumed that the wind turbine and related electric components (such as precision instruments etc.) are imported although Austria has some specialised component suppliers. For coal and gas power plants no investment costs are assumed as only existing plants are considered.

Maintenance costs and other operating costs are included in the analysis as major cost categories (see Table 7.6). Operating costs change over the life cycle of the wind turbine. In the first two years, no maintenance costs are assumed. From the third to the twelfth year maintenance costs of 0.87 €cent/kWh are assumed; afterwards maintenance costs approximately double. Other operating costs are taken to be 0.85 €cent/kWh over the whole life cycle of the wind turbine. Average operating costs per wind turbine are hence 68,910 € p.a. Total operating costs (for 364 wind turbines) rise to 25.1 million € by 2020 (see Table 7.4). Operating costs of wind turbines are hence approximately 43 million € below the operating costs of the reference technologies (coal and gas power plants). As already stated this is however a rather conservative estimate as fossil fuel prices – which account for the largest share in the operating costs of coal and gas power plants – are assumed to remain constant until 2020.

Table 7.4: Technology Wedge E-1: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4
Additional Costs	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4	80.4
Operating costs	1.1	2.2	4.5	6.8	9.1	11.4	13.7	15.9	18.2	20.5	22.8	25.1
Additional Costs	-4.6	-9.2	-12.6	-16.0	-19.4	-22.9	-26.3	-29.7	-33.1	-36.6	-40.0	-43.4

Source: Own calculations based on Ecofys et. al (forthcoming), IG Windkraft (2009) and RENERGIE (2009).

Table 7.5: Technology Wedge E-1: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Machinery and equipment n.e.c.	0.8	0.8	0.8	0.8
Electrical machinery and apparatus n.e.c.	79.1	79.1	79.1	79.1
Medical, precision and optical instruments etc.	0.5	0.5	0.5	0.5
Construction work	13.8	0.0	13.8	0.0
Land transport; transport via pipeline services	3.0	0.0	3.0	0.0
Other business services	2.7	0.0	2.7	0.0
Total	100.0	80.4	100.0	80.4

Source: Own calculations based on IG Windkraft (2009).

Table 7.6: Technology Wedge E-1: Disaggregation of operating costs

Category	Av erage share in total operating costs in %	Av erage share in additional oc in %
Fuel costs	0.0	-222.4
Maintenance cost	52.4	32.5
Other	47.6	89.9
Total	100.0	-100.0
Persons employed (full time equiv alents)	-	-6

Source: Own calculations based on IG Windkraft (2009) and RENERGIE (2009).

Cost appraisal

Based on data for the investment and operating phase electricity generation costs for a 2 MW wind turbine are analysed. For the calculations 2,200 full load hours per year and a service life of 25 years are assumed.

Electricity generation costs (C) per kWh output are calculated following a cost comparison method based on the following equation

$$C = C_k + C_f + C_v$$

where C_k denotes the user costs of capital (annual interest rate and depreciation over the assumed service life, C_k = r + d), C_f denotes other fixed costs like maintenance and upkeep/servicing costs and C_v denotes variable costs[42]. In order to illustrate the sensitivity with respect to the interest rate, two alternatives are calculated, alternative A with an assumed real interest rate of 5% and alternative B with an interest rate of 2.5%.

Investment costs per kW are 1,325 €. Annual maintenance and upkeep/servicing costs are 1.4% and 1.3% of investment costs respectively (see Table 7.7). Based on a service life of 25 years user costs of capital amount to 5.4 €cent/kWh with an assumed interest rate of 5% and to 3.9 €cent/kWh with an interest rate of 2.5%. Maintenance and servicing costs are 0.84 and 0.8 €cent/kWh respectively. Total costs of electricity generation amount to 7.1 €cent/kWh for a 5% interest rate and to 5.6 €cent/kWh for an interest rate of 2.5%.

[42] For wind turbines, however, there are no variable costs.

Table 7.7: Cost appraisal wind power with alternative interest rates

Wind power		**2009**	**2020**
Investments			
Interest rate	% p.a.	5.0	2.5
Investment costs (IC)	€ / kWel	1,325.00	1,325.00
Operating			
Maintenance costs p.a.	% IC	1.40	1.40
Other fixed costs p.a.	% IC	1.33	1.33
Operating costs p.a.	% IC	-	
User costs of capital	**€ct / kWh**	*5.42*	*3.91*
Other fixed costs	*€ct / kWh*	*1.64*	*1.64*
Variable costs	*€ct / kWh*	*0.00*	*0.00*
Total costs	***€ct / kWh***	***7.06***	***5.56***

Source: Own calculations based on Ecofys et al. (forthcoming) and IG Windkraft (2009).

7.2.2 Technology Wedge E-2: Substitution of fossil electricity generation by run-of-river hydro plants

For this technology wedge the storyline assumes a substitution of electricity from existing coal and gas fired power plants[43] by electricity from run-of-river plants. The characteristics of the wedge are summarised in Table 7.8.

Table 7.8: Summary Table for Technology Wedge E-2

Substitution of fossil electricity generation by run-of-river hydro plants	
Substitution of fossil electricity	2.5 PJ of coal and 3.3 PJ of gas based electricity generation are substituted by hydropower
Technology	Run-of-river plants on different scales (ranging from 2 to 88 MW)
Required capacity increase*	346 MW
Diffusion path	Gradual
Total investment	1,043 million € by 2020
Operating costs	26.1 million € in 2020
Emission reduction by wedge*	1 million t CO_2 in 2020

* Compared to the reference scenario.

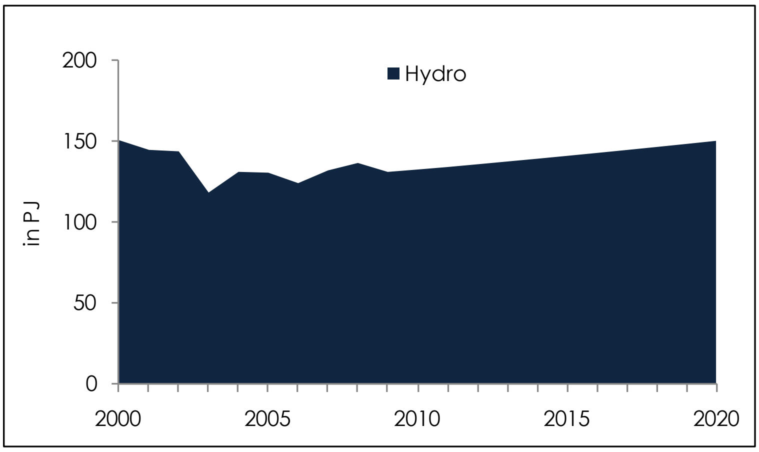
Due to geographical factors hydropower has a long tradition in Austria and accounts for the country's largest share in renewable energy sources. In 2008 hydropower contributed 137 PJ (56%) to total Austrian electricity generation. Additional technical-economic hydropower potential is estimated in the range of 64.4 PJ (Pyöri, 2008). In the reference scenario hydropower is estimated to increase by 13 PJ to 150 PJ[44] (see Figure 7.17). This leaves an

[43] The same qualifications apply as in Technology Wedge E-1.

[44] This equals maximum electricity production from hydropower plants in 2000.

unused technical-economic potential of 51 PJ which is, however, reduced to 33 PJ because of ecological aspects and environmental regulation (see e.g. Pyöri, 2008). The Austrian 'Energy Strategy' states that by 2015 through repowering and construction of new plants annual hydroelectricity generation shall be increased by 15 PJ compared to 2008 levels (BMLFUW – BMWFJ, 2010).

Figure 7.17: Development of transformation output from hydropower – reference scenario



Source: Statistics Austria (2009a, b); own calculations.

Technology Wedge E-2 analyses the substitution of coal and gas based electricity generation by hydropower. The underlying storyline thus assumes a replacement of electricity generation from existing coal and gas power plants of energy producing companies by an extension of hydropower. Just as for Technology Wedge E-1 "Wind power" this change results in lower CO_2 emissions due to a substitution of fossil fuels by a zero emission energy source.

These effects again depend considerably on the technological characteristics of the existing and new technologies. For this technology wedge the following assumptions are made: Only a replacement of existing coal and gas power plants is analysed. Efficiency factors of these plants are held constant until 2020. Potential efficiency gains through retrofitting of existing plants are hence not depicted. Therefore, efficiency gains and emission reductions through the substitution of these technologies can be interpreted as maximum effects. Furthermore, only new-built hydropower plants are considered. Nevertheless, one has to keep in mind that electricity generation from run-of-river plants can also be increased by repowering existing plants. The additional electricity generation potential from repowering is estimated at 2.5 PJ by 2015 (BMWFJ, 2010).

Implementation of EnergyTransition methodology for Technology Wedge E-2

Table 7.9 and Figure 7.18 summarise changes in these variables for Technology Wedge E-2: For the technology wedge total electricity output is assumed to remain constant, but a substitution of electricity from fossil power plants by hydropower occurs. Transformation output of coal and gas fired power plants hence decreases by 18% while hydropower transformation output increases by 4%. Transformation efficiency is held constant for the different technologies. Transformation input from coal and gas power plants decreases by 18% while transformation input of run-of-river plants increases by 4% which yields a reduction in overall transformation input by 2% compared to 2008 (Δt).

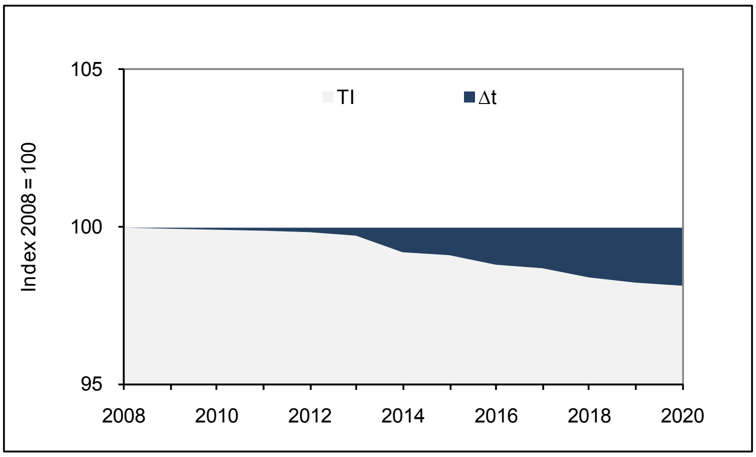
Table 7.9: Technology Wedge E-2: Summary of energy indicators

Substituting Single Coal and Gas Electricity Generation by Hydro Power - gradual diffusion	2008 2008=100	2020/2008 %	2020 2008=100
Transformation Output (TO)	**100**	**0**	**100**
Coal	100	-18	82
Gas	100	-18	82
Hydro	100	4	104
Transformation Input (TI)	**100**	**-2**	**98**
Coal	100	-18	82
Gas	100	-18	82
Hydro	100	4	104

Source: Statistics Austria (2009a), UNFCCC (2010); own calculations.

Figure 7.18 illustrates changes in the index of transformation input until 2020[45]. These index values can then be transformed into absolute changes in transformation input compared to 2008 and may also be compared to the EnergyTransition reference scenario. Using emission factors by energy source (UNFCCC, 2010) and changes in absolute transformation input emission reductions from this technology wedge are then calculated.

Figure 7.18: Technology Wedge E-2: Effects on transformation input[1]



Source: Statistics Austria (2009a), UNFCCC (2010); own calculations. – [1] Δt describes the effect of changes in transformation efficiency on transformation input. TI is transformation input.

[45] For all indices 2008=100 (see Part B chapter 3).

In the storyline for this technology wedge, the capacity of hydropower plants considered ranges from 2 MW to 88 MW. All plants represent already planned installations as listed in VEÖ (2009) and Berlakovich (2009). This is important as the potential size of the plant depends on its specific location along the course of the river etc. Moreover, the technical-economic potential is also limited through environmental regulation (see above).

For various size classes different full load hours are assumed according to e-control (2009b) (see Table 7.10).

Table 7.10: Average full load hours of run-of-river plants by plant size

Capacity	1 - 2.5 MW	2.5 - 5 MW	5 - 10 MW	10 - 20 MW	20 - 30 MW	30 - 40 MW	40 - 50 MW	50 - 80 MW	80 - 100 MW
Full load hours p.a.	4,615	4,735	4,796	4,751	4,770	4,668	4,706	4,309	4,594

Source: E-control (2009b).

Similar to wind power, electricity generated from hydropower plants can show fluctuations. Fluctuations due to changes in hydrolicity, however, occur not only on a seasonal basis but also on an annual basis. Due to these fluctuations run-of-river plants also require the installation of backup systems that can provide electricity in case of a hydropower shortfall. Again a broad range of technologies can in principle be used as back-up systems for hydropower. The pros and cons of different backup systems are discussed in the context of the technology wedge "Wind power" (chapter 7.2.1).

As for wind power, for this technology wedge the option of pumped-storage hydroelectricity generation is considered. For the economic evaluation of the investment and operating phase the system boundary nevertheless only covers additionally installed run-of-river plants.

Assuming a reduction of CO_2 emissions of 1 million t by 2020 through this technology wedge compared to emissions in the reference scenario requires that 2.5 PJ electricity from coal power plants and 3.3 PJ from gas power plants are substituted by hydro power. This implies that additional 346 MW of hydropower have to be installed by 2020 compared to the reference scenario.

In this wedge a gradual diffusion of additional hydropower starting in 2009 is assumed following the estimated completion dates provided by VEÖ (2009) and Berlakovich (2009). In 2020 5.8 PJ of electricity is generated by the new run-of-river plants given the full load hours listed in Table 7.10. Electricity output from coal power plants in return is reduced by 2.5 PJ and electricity output from gas power plants by 3.3 PJ respectively. Coal and gas input in existing plants hence is reduced by 7.7 PJ and 4.9 PJ respectively[46] in 2020 compared to the reference scenario.

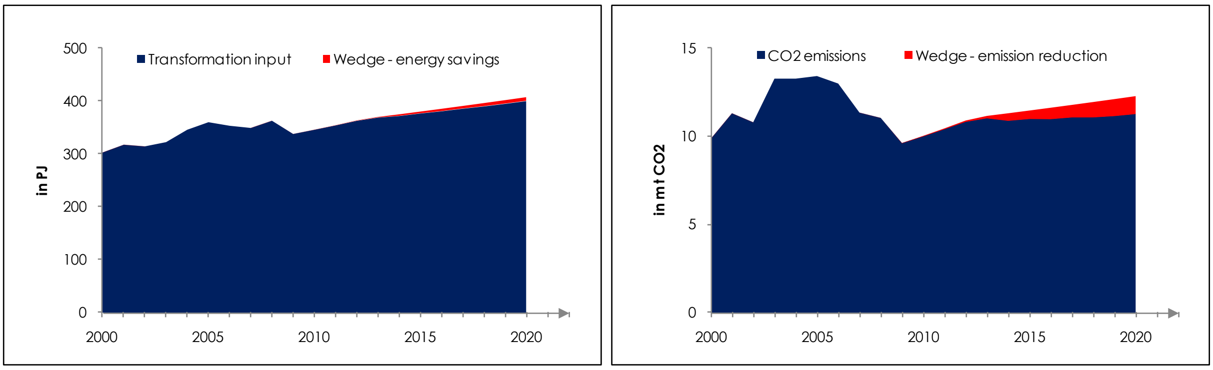
According to the emission factor of 97 t CO_2/TJ for coal and 55 t CO_2/TJ for gas (UNFCCC, 2010) the reduction in transformation input is equivalent to a reduction of 1 million t CO_2 by

[46] This transformation input again reflects the efficiency factors of 43% and 51% from the Austrian Energy Balances 2008.

2020. 0.7 million t CO_2 are reduced by the substitution of coal by hydropower and 0.3 million t CO_2 are reduced by the substitution of gas. Over the whole period 2008-2020 this wedge reduces 5.7 million t CO_2 compared to the reference scenario. Compared to wind power with a total accumulated emission reduction of 7 million t CO_2 by 2020, Technology Wedge E-2 delivers a smaller reduction due to differences in the assumed diffusion path of the technology (gradual diffusion instead of linear diffusion).

Table 7.11 and Figure 7.19 summarise the effects of the implementation of Technology Wedge E-2 on transformation input and related CO_2 emissions.

Figure 7.19: Technology Wedge E-2: Effects on transformation input (left) and CO_2 emissions (right) in energy generation



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 7.11: Technology Wedge E-2: Effects on transformation input and related CO_2 emissions

Energy source	Transformation input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Fossil Fuels	**136.34**	**139.60**	**-12.43**	**-8.2**	**9.69**	**9.76**	**-1.00**	**-9.3**
Coal	47.48	44.11	-7.61	-14.7	4.61	4.28	-0.74	-14.7
Oil	8.58	10.04	0.00	0.0	0.67	0.78	0.00	0.0
Gas	80.28	85.44	-4.82	-5.3	4.42	4.70	-0.27	-5.3
Renewables	**226.83**	**260.74**	**5.77**	**2.3**	**1.34**	**1.50**	**0.00**	**0.0**
Wastes	13.38	15.02	0.00	0.0	1.34	1.50	0.00	0.0
Biofuels	68.76	78.50	0.00	0.0	0.00	0.00	0.00	
Hydro	136.60	156.11	5.77	3.8	0.00	0.00	0.00	
Wind	7.19	9.87	0.00	0.0	0.00	0.00	0.00	
PV	0.07	0.10	0.00	0.0	0.00	0.00	0.00	
Other	0.83	1.14	0.00	0.0	0.00	0.00	0.00	
Total	**363.17**	**400.33**	**-6.66**	**1.6**	**11.03**	**11.26**	**-1.00**	**-8.2**

Source: Own calculations.

Economic aspects

Investment and operating costs of run-of-river plants are presented in Tables 7.11 to 7.13. Investment costs are calculated based on Kleinwasserkraft Österreich (2009) and Kaltschmitt (2009), operating costs are calculated based on Austrian Energy Agency (2009). Operating costs of the reference technologies are based on RENERGIE (2009). Again all costs – including fuel costs – are held constant until 2020. The assumption of constant fuel prices again directly influences the additional operating costs of the technology wedge which would be even higher with increasing fossil fuel prices.

Table 7.12 shows the development of investment and operating costs of run-of-river plants until 2020. The cost development follows the gradual diffusion path of the hydropower plants. Over the whole period 2009 to 2020 investment costs for run-of-river plants amount to 1,043 million €. As a substitution of electricity and heat from existing coal power plants and heat plants is assumed in the technology wedge all investments are additional costs. The disaggregation of investment costs in cost categories depends on many factors such as the type or the number of hydroelectric turbines and the specific location of the plant. Following Kleinwasserkraft Österreich (2009) we assume that on average 60% of investment costs accrue to the construction sector and the remaining 40% accrue to the sectors machinery and electrical machinery and apparatus.[47] For both cost categories import shares are relatively low.

Assuming maintenance costs of 1% of investment costs and other operating costs of 1.5% of investment costs, total operating costs for Technology Wedge E-2 are 26.1 million € in 2020. Compared to the reference technologies – electricity production by coal and gas fired power plants – operating costs of 42.5 million € can be saved by 2020. These cost savings accrue to savings in fuel costs and maintenance costs, the other operating costs of the run-of-river plants slightly exceed those of the reference technologies. As price increases of fossil fuels can be assumed by 2020 (e.g. IEA, 2009; DG TREN, 2010) (see above) and the calculations are based on constant prices estimates for cost savings are rather conservative.

[47] Kleinwasserkraft Österreich (2009) estimates the share of construction in total investment costs between 60% and 70%, remaining investment costs accrue to machinery and electronics. Using data from Kaltschmitt et al. (2009) the average share of construction activities in investment cost is 55%, the remaining 45% of investment costs are again for the machinery. We hence assume a 60% to 40% distribution for construction activities and the machinery.

Table 7.12: Technology Wedge E-2: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs	18.0	19.5	19.5	48.0	123.0	282.0	96.0	24.5	129.0	178.0	31.0	75.0
Additional Costs	18.0	19.5	19.5	48.0	123.0	282.0	96.0	24.5	129.0	178.0	31.0	75.0
Operating costs	0.5	0.9	1.4	2.6	5.7	12.8	15.2	15.8	19.0	23.4	24.2	26.1
Additional Costs	-0.8	-1.5	-2.2	-4.3	-9.5	-21.0	-25.1	-26.1	-31.5	-38.0	-39.3	-42.5

Source: Own calculations based on Kleinwasserkraft Österreich (2009), Austrian Energy Agency (2009), Kaltschmitt (2009).

Table 7.13: Technology Wedge E-2: Disaggregation of investment costs

Sector	Total Costs		Additional Costs	
	Average share in investment costs in %	Average import share of good/service in %	Average share in investment costs in %	Average import share of good/service in %
Machinery and equipment n.e.c. Electrical machinery and apparatus n.e.c.	40.0	4.0	40.0	4.0
Construction work	60.0	3.0	60.0	3.0
Total	100.0	7.0	100.0	7.0

Source: Own calculations based on Kleinwasserkraft Österreich (2009).

Table 7.14: Technology Wedge E-2: Disaggregation of operating costs

Category	Average share in total operating costs in %	Average share in additional oc in %
Fuel costs	0.0	-124.5
Maintenance cost	52.4	1.0
Other	47.6	23.5
Total	100.0	-100.0

Source: Own calculations based on Austrian Energy Agency (2009).

Cost appraisal

For Technology Wedge E-2, based on data for the investment and operating phase electricity generation costs for a 6 MW run-of-river plant are exemplarily analysed. For the cost appraisal 4,796 full load hours per year (see Table 7.10) and a service life of 50 years are assumed. The results are highly sensitive to parameters like assumed service life and interest rate. In order to illustrate the sensitivity with respect to the interest rate, two alternatives are calculated: alternative A with an assumed real interest rate of 5% and alternative B with an interest rate of 2.5%.

Following Kleinwasserkraft Österreich (2009) investment costs of 3,250 €/kW are assumed. Annual maintenance and servicing costs are 1% and 1.5% of investment costs respectively (see Table 7.17). Based on an annual interest rate of 5% and a service life of 50 years user costs of capital amount to 4.7 €cent/kWh, with an assumed interest rate of 2.5% user cost of capital are 3 €cent/kWh. Maintenance and other fixed costs are 0.7 and 1 €cent/kWh respectively. Total costs per kWh electricity hence amount to 6.4 €cent/kWh with an interest rate of 5% and 4.7 €cent/kWh with a 2.5% interest rate.

Table 7.15: Cost appraisal hydropower with alternative interest rates

Run-of-river plant		2009	2020
Investments			
Interest rate	% p.a.	5.0	2.5
Inv estment costs (IC)	€ / kWel	3,250.0	3,250.0
Operating			
Maintenance costs p.a.	% IC	1.0	1.0
Other fixed costs p.a.	% IC	1.5	1.5
Operating costs p.a.	% IC	-	
User costs of capital	**€ct / kWh**	*4.74*	*3.05*
Other fixed costs	*€ct / kWh*	*1.69*	*1.69*
Variable costs	*€ct / kWh*	*0.00*	*0.00*
Total costs	***€ct / kWh***	***6.44***	***4.74***

Source: Own calculations based on Kleinwasserkraft Österreich (2009), Austrian Energy Agency (2009) and e-control (2009b).

7.2.3 Technology Wedge E-3: Substitution of coal based electricity generation and gas based heat generation by biomass and biogas CHPs

For this technology wedge the storyline assumes a substitution of coal based electricity generation and gas based heat generation by electricity[48] and heat from biomass and biogas CHPs. The characteristics of the wedge are summarised in Table 7.16.

Table 7.16: Summary Table for Technology Wedge E-3

Substitution of coal based electricity generation and gas based heat generation by biomass and biogas CHPs	
Substitution of fossil electricity	2.5 PJ of coal based electricity generation and 5.2 PJ of gas based heat generation are substituted by biomass and biogas CHPs
Technology	Biomass and biogas plants on different scales (biogas 2 MW, biomass 7 - 29 MW)
Required capacity increase*	397 MW
Diffusion path	Gradual
Total investment	738 million € by 2020
Operating costs	117 million € in 2020
Emission reduction by wedge*	1 million t CO_2 in 2020

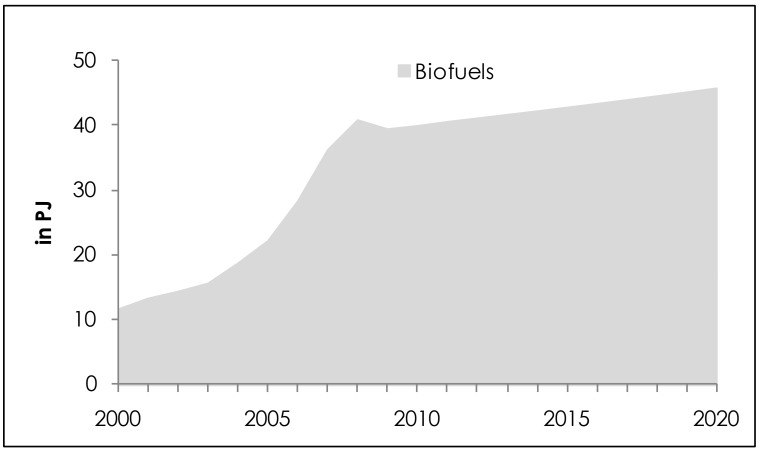
* Compared to the reference scenario.

[48] The same qualifications apply as in Technology Wedge E-1 and E_2.

The use of biomass in Austria increased significantly over the last years. This does not only apply to increased biofuel and biomass use for final energy consumption, but also to heat and electricity generation. Between 2000 and 2008 transformation output from biomass increased from 12 PJ to 41 PJ – 16 PJ electricity and 25 PJ heat. In the reference scenario transformation output from biomass is assumed to rise to 46 PJ by 2020 (see Figure 7.20).

For Austria, the available biomass potential is estimated in the range of 186 to 272 PJ until 2020 (WIFO et al., 2007). For biogas a potential of 68 PJ is assumed (Austrian Compost & Biogas Association, 2009).

Figure 7.20: Development of transformation output from biofuels – reference scenario



Source: Statistics Austria (2009a, b); own calculations.

Technology Wedge E-3 analyses the substitution of coal based electricity generation and gas based heat generation by biomass and biogas CHPs. The underlying storyline assumes a replacement of electricity generation from existing coal fired power plants and heat generation in existing gas fired heat plants of energy producing companies by an increased implementation of biomass and biogas plants. CO_2 emissions are reduced due to a substitution of fossil fuels by renewables.

For this technology wedge the following assumptions are made: Only a replacement of existing coal power plants and gas heat plants is analysed. Efficiency factors of these plants – 43% for coal power plants and 64% for gas heating plants (Statistics Austria, 2009a) – are held constant until 2020.

Implementation of EnergyTransition methodology for Technology Wedge E-3

Table 7.17 and Figure 7.21 summarise changes in the variables transformation input and transformation output for Technology Wedge E-3: For the technology wedge total electricity and heat output is assumed constant, but a substitution of energy from fossil power plants by biomass and biogas cogeneration occurs. Transformation output of coal power plants decreases by 13% and transformation output from gas heat plants decreases by 85% while transformation output from biofuel CHPs increases by 53%. Transformation efficiency is assumed to remain constant for coal and gas plants. For existing coal fired power plants and gas fired heat plants transformation input decreases by 13% and 85% respectively. Transformation input of biomass and biogas plants increases by 56% which yields a reduction in overall transformation input by 1% compared to 2008 (Δt).

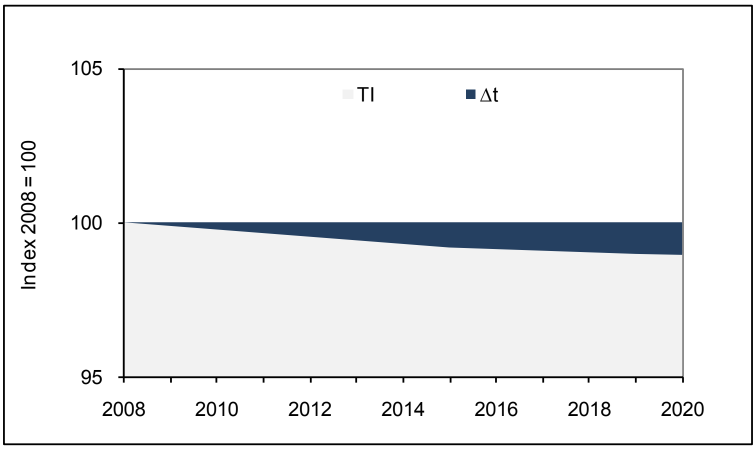
Table 7.17: Technology Wedge E-3: Summary of energy indicators

Substituting Single Fossil Energy Generation by Biomass and Biogas - gradual diffusion	**2008** 2008=100	**2020/2008** %	**2020** 2008=100
Transformation Output (TO)	**100**	**0**	**100**
Coal	100	-13	87
Gas	100	-85	15
Biofuels	100	53	153
Transformation Input (TI)	**100**	**-1**	**99**
Coal	100	-13	87
Gas	100	-85	15
Biofuels	100	56	156

Source: Statistics Austria (2009a), UNFCCC (2010); own calculations.

Figure 7.21 illustrates changes in the index of transformation input until 2020 with 2008 = 100. The index values can be transformed into absolute changes in transformation input compared to 2008 and may also be compared to the reference scenario. Using emission factors by energy source (UNFCCC, 2010) and changes in absolute transformation input emission reductions from this technology wedge are then calculated.

Figure 7.21: Technology Wedge E-3: Effects on transformation input[1]



Source: Statistics Austria (2009a), UNFCCC (2010); own calculations. – [1] Δt describes the effect of changes in transformation efficiency on transformation input. TI is transformation input.

In the storyline for this technology wedge four different types of cogeneration plants are considered (see Table 7.18). Technology data for biomass plants are taken from Obernberger and Thek (2008) who carried out an economic evaluation of ten different biomass CHPs. Three different biomass plants were selected for the wedge based on plant efficiency and cost effectiveness. Plant type 2 (see Table 7.18) was chosen because of the relatively high electric capacity compared to the heat capacity as in the future heat demand will decrease (e.g. due to more efficient buildings or heating systems) while electricity demand can be expected to stay constant or to increase further due to life style or technology changes (higher electricity demand in passive houses, more electric household appliances, electric vehicles). Data for the biogas CHP considered was provided by Austrian Compost & Biogas Association.

Table 7.18: Technical parameters of considered biomass and biogas plants

	Type 1	Type 2	Type 3	Type 4
Technology	biomass combustion	biomass combustion	biomass gasification	biogas
Electric capacity	5.0 MW	4.5 MW	2.1 MW	1.0 MW
Heat capacity	18.0 MW	5.0 MW	3.7 MW	1.2 MW
Efficiency factor	86.0%	70.7%	82.5%	85.0%

Source: Obernberger and Thek (2008), Austrian Compost & Biogas Association (2010).

Following Obernberger and Thek (2008) and Austrian Compost & Biogas Association (2010) for biomass plants 6,000 full load hours and for biogas plants 8,000 full load hours are assumed. Biomass CHPs are assumed to use the energy source wood chips, for biogas CHPs energy crops and animal substrates are used.

In contrast to the other technology wedges considered for electricity and heat – wind power and hydropower – biomass and biogas are not intermittent energy sources. The demand for heat, however, fluctuates – mainly on a seasonal basis. In order to realise the efficiency potentials of cogeneration plants high capacity utilisation is required. An extension of cogeneration plants to trigeneration plants that jointly produce electricity, heating and cooling would be a solution to this issue.

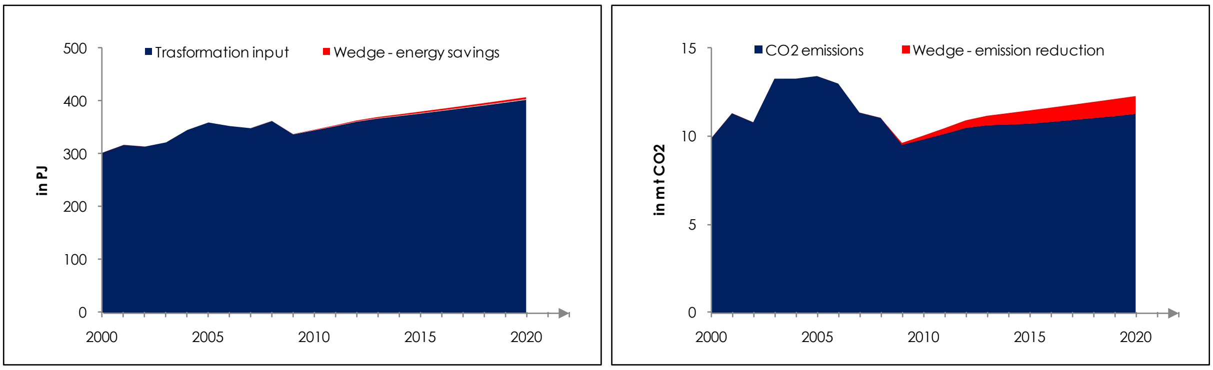
A reduction of CO_2 emissions of 1 million t by 2020 through this technology wedge compared to emissions in the reference scenario requires that 2.5 PJ electricity from coal fired power plants and 5.2 PJ from gas fired heat plants are substituted by electricity and heat produced in biomass and biogas CHPs. This implies that the capacity of biomass and biogas plants has to be increased by 397 MW by 2020 compared to the reference scenario.

In this wedge a gradual diffusion of additional biomass and biogas cogeneration plants starting in 2009 is assumed: Between 2009 and 2015 each year four bio-energy CHPs are built (one of each technology type listed in Table 7.18). Between 2016 and 2019 two CHPs of the technology types 2, 3 and 4 and one CHP of technology 1 are constructed. In 2020 two bio-energy CHPs of type 2 and 4 and 1 CHP of technology type 1 and 3 are built. In 2020 2.5 PJ of electricity and 5.2 PJ of heat are generated by these new CHPs assuming 6,000 full load hours for biomass plants and 8,000 full load hours for biogas plants. Electricity output from coal power plants in return is reduced by 2.5 PJ and heat output from gas heat plants by 5.2 PJ. Assuming efficiency factors of 43% for coal power plants and 64% for gas heat plants, coal and gas input hence is reduced by 5.7 PJ and 8.2 PJ respectively in 2020 compared to the reference scenario.

This reduction in transformation input is equivalent to a reduction of 1 million t CO_2 by 2020 using emission factors of 97 t CO_2/TJ for coal and 55 t CO_2/TJ for gas (UNFCCC, 2010). 0.6 million t CO_2 are reduced by the substitution of coal power plants and 0.5 million t CO_2 are reduced by the substitution of gas heat plants. Over the whole period 2008-2020 this wedge reduces 7.6 million t CO_2 compared to the reference scenario.

Table 7.19 and Figure 7.22 summarise the effects of the implementation of Technology Wedge E-3 on transformation input and related CO_2 emissions.

Figure 7.22: Technology Wedge E-3: Effects on transformation input (left) and CO_2 emissions (right) in energy generation



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 7.19: Technology Wedge E-3: Effects on transformation input and related CO_2 emissions

Energy source	Transformation input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Fossil Fuels	**136.34**	**138.13**	**-13.90**	**-9.1**	**9.69**	**9.76**	**-1.00**	**-9.3**
Coal	47.48	46.04	-5.68	-11.0	4.61	4.47	-0.55	-11.0
Oil	8.58	10.04	0.00	0.0	0.67	0.78	0.00	0.0
Gas	80.28	82.05	-8.22	-9.1	4.42	4.51	-0.45	-9.1
Renewables	**226.83**	**265.20**	**10.23**	**4.0**	**1.34**	**1.50**	**0.00**	**0.0**
Wastes	13.38	15.02	0.00	0.0	1.34	1.50	0.00	0.0
Biofuels	68.76	88.73	10.23	13.0	0.00	0.00	0.00	
Hydro	136.60	150.33	0.00	0.0	0.00	0.00	0.00	
Wind	7.19	9.87	0.00	0.0	0.00	0.00	0.00	
PV	0.07	0.10	0.00	0.0	0.00	0.00	0.00	
Other	0.83	1.14	0.00	0.0	0.00	0.00	0.00	
Total	**363.17**	**403.33**	**-3.66**	**-0.9**	**11.03**	**11.26**	**-1.00**	**-8.2**

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic aspects

Investment and operating costs of biomass and biogas CHPs that are the input parameters for the input-output analysis in Part B, chapter 9 are presented in Tables 7.18 to 7.20. Cost data for biomass plants are taken from Obernberger and Thek (2008) and Ecofys et al. (forthcoming), cost data for biogas are from Austrian Compost & Biogas Association (2010). Operating costs of the reference technologies are based on RENERGIE (2009) for coal fired power plants and on Twele et al. (2009) for gas fired heat plants.

Again for all energy sources no price changes are assumed. This applies to all cost data (investment and operating costs) which are assumed constant until 2020. However, due to the scarcity of fossil energy sources and environmental regulation (e.g. the pricing of CO_2 emissions in the EU ETS) fossil fuel prices can be expected to show higher increases than biomass prices. This implies that additional operating costs may be lower than depicted in this technology wedge.

Table 7.20 shows the development of investment and operating costs of biomass and biogas plants up to 2020. The cost development follows the diffusion path of the technologies in the technology wedge: Between 2009 and 2015 each year four bio-energy CHPs are built (one of each technology type listed in Table 7.18) which amounts to investment costs of 51.1 million € p.a. Between 2016 and 2019 two CHPs of the technology types 2, 3 and 4 and one CHP of technology 1 are built which requires an annual investment of 69.1 million €. In 2020 two bio-energy CHPs of type 2 and 4 and 1 CHP of technology type 1 and 3 are built which causes investments of 65.5 million €. Over the whole period 2009 to 2020 investment costs for biomass and biogas CHPs amount to 657 million €. As a substitution of electricity and heat from existing coal power plants and heat plants is assumed in the technology wedge all investments are additional costs. For biomass CHPs, machinery has the largest share in average investment costs (61%) followed by construction work (31%). Other investment costs accrue to the sectors other business services (8%) and vehicles (0.3%). For biomass plants import shares are relatively low in all investment categories except machinery with an import share of 75% (see Table 7.21). For biogas CHPs construction work and machinery have the largest shares in investment costs (45% and 40% respectively). Investment costs in the sectors other business services account for 5% and 10%. For biogas, import shares are relatively low in all investment categories. The highest share in additional costs accrues to machinery (58%) followed by construction work (33%).

Total operating costs for this technology wedge amount to 116.8 million € in 2020. Fuel costs account for the largest share in operating costs (67% for biomass CHPs and 70% for biogas CHPs, see Table 7.22) and are significantly below the fuel costs for the reference technologies. Therefore despite higher maintenance and other operating costs aggregate operating costs for bio-energy plants are below those of coal and gas plants assuming constant 2008 costs – and hence constant cost ratios of the different fuels – for the period until 2020.

Table 7.20: Technology Wedge E-3: Development of investment and operating costs (in million €)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Investment costs biomass	46.3	46.3	46.3	46.3	46.3	46.3	46.3	69.1	69.1	69.1	69.1	55.9
Investment costs biogas	4.8	4.8	4.8	4.8	4.8	4.8	4.8	9.6	9.6	9.6	9.6	9.6
Additional Costs	51.1	51.1	51.1	51.1	51.1	51.1	51.1	78.7	78.7	78.7	78.7	65.5
Operating costs biomass	7.1	14.2	21.4	28.5	35.6	42.7	49.8	60.2	70.6	81.0	91.4	100.3
Operating costs biogas	1.0	2.0	2.9	3.9	4.9	5.9	6.8	8.8	10.7	12.7	14.6	16.6
Additional Costs	-1.7	-3.3	-5.0	-6.6	-8.3	-9.9	-11.6	-13.0	-14.5	-15.9	-17.4	-19.0

Source: Own calculations based on Obernberger and Thek (2008), Ecofys et al. (forthcoming), Austrian Compost & Biogas Association (2010), RENERGIE (2009) and Twele et al. (2009).

Table 7.21: Technology Wedge E-3: Disaggregation of investment costs

Sector	Total Costs Biomass		Total Costs Biogas		Additional Costs (Biomass and Biogas)	
	Avg. share in investment costs in %	Avg. import share of good/service in %	Avg. share in investment costs in %	Avg. import share of good/service in %	Avg. share in investment costs in %	Avg. import share of good/service in %
Construction work	31.0	4.5	45.0	0.0	32.5	4.0
Machinery	60.7	34.0	40.0	6.0	58.4	30.9
Other business services	8.0	0.1	5.0	0.5	7.6	0.1
Vehicles	0.3	0.3	10.0	2.5	1.4	0.6
Total	100.0	38.9	100.0	9.0	100.0	35.6

Source: Own calculations based on Obernberger and Thek (2008) and Austrian Compost & Biogas Association (2010).

Table 7.22: Technology Wedge E-3: Disaggregation of operating costs

Category	Biomass Avg. share in total operating costs in %	Biogas Avg. share in total operating costs in %	Biomass and Biogas Avg. share in additional o.c. in %
Fuel costs	66.7	70.1	-185.2
Maintenance cost	13.6	11.6	25.0
Other	19.8	18.3	60.2
Total	100.0	100.0	-100.0

Source: Own calculations based on Obernberger and Thek (2008), Ecofys et al. (forthcoming), Austrian Compost & Biogas Association (2010), RENERGIE (2009) and Twele et al. (2009).

7.2.4 Technology Wedge E-4: Reduction in electricity and heat generation through reduced demand

Technology Wedge E-4 analyses a reduction of electricity and heat generation induced by reduced final demand. The characteristics of the technology wedge are summarised in Table 7.23.

Table 7.23: Summary Table for Technology Wedge E-4

Reduction in electricity and heat generation through reduced demand	
Reduction of electricity and heat generation	85 PJ of fossil transformation input are reduced due to reduced demand for electricity and heat
Technology	No change in currently employed technologies
Required capacity increase	Not applicable
Diffusion path	Gradual
Total investment	Not applicable
Operating costs	Not applicable
Emission reduction by wedge*	7 million t CO_2 in 2020

* Compared to the reference scenario.

Technology Wedge E-4 deviates from the other technology wedges in the energy sector as it takes the energy savings potential and thus reduced energy demand of the combined technology wedges for the sectors mobility, buildings and manufacturing as a starting point. In the combination of technology wedges in WP1 to WP3 electricity and heat are reduced by 30 PJ and 6 PJ respectively in 2020 compared to the reference scenario. The changes in electricity and heat demand resulting from the specific storylines and technology wedges in the areas mobility, buildings and industry are listed in Table 7.24. Technology Wedge E-4 illustrates the interdependencies of the various levels in the energy cascade. From mobility an additional electricity demand results due to e-mobility that has to be provided from the electricity and heat work package, whereas from the building and industry sectors less electricity and heat is demanded.

Table 7.24: Technology Wedge E-4: Feasible combinations of demand wedges

		Sectoral contribution to E-4 Changes in final energy consumption compared to reference			
		Electricity		Heat	
		in PJ	in %	in PJ	in %
WP1	Mobility	2.20	7		
WP2	Buildings	-12.47	-41	-4.48	-74
WP3	Industry	-19.93	-66	-1.54	-26
	Total	**-30.19**	**-100**	**-6.03**	**-100**

Source: Own calculations.

Starting from this reduced final energy demand and assuming constant distribution losses transformation output of electricity and heat in this wedge can be decreased by 36 PJ and 7 PJ in 2020. It is assumed that electricity from coal and gas fired power plants as well as from coal and oil fired CHPs is reduced. Furthermore it is presumed that heat from oil and gas fired heating plants as well as from coal and oil fired CHPs is reduced.[49] Transformation input in coal based plants hence decreases by 44 PJ in 2020 compared to the EnergyTransition reference scenario, transformation input in oil and gas based plants is reduced by 7 PJ and 35 PJ respectively.

Implementation of EnergyTransition methodology for Technology Wedge E-4

Table 7.25 and Figure 7.23 show the changes in transformation input and output for Technology Wedge E-4: As final energy demand for heat and electricity is reduced by the combination of technology wedges in WP1 to WP3 and assuming constant distribution losses, total transformation output is reduced by 15% by 2020. It is assumed that only electricity and heat from fossil fuel based energy generation is substituted: Transformation output of coal decreases by 88% and transformation output of oil and gas by 79% and 33% respectively.

Transformation efficiency is assumed constant for all plant types. Overall efficiency, however, increases as primarily energy supply from single-generation plants is reduced.

Transformation input of coal declines by 92%, transformation input of oil and gas by 82% and 43% respectively. Overall transformation input decreases by 23% compared to 2008 (Δt) through reduced transformation input and increased efficiency.

[49] Technology Wedge E-4 assumes a reduction in heat output from CHPs only because the potential for reduction of heat from heating plants is already exploited. It is further assumed that a proportionate decrease in electricity output of the CHPs occurs in order to maintain constant efficiency factors.

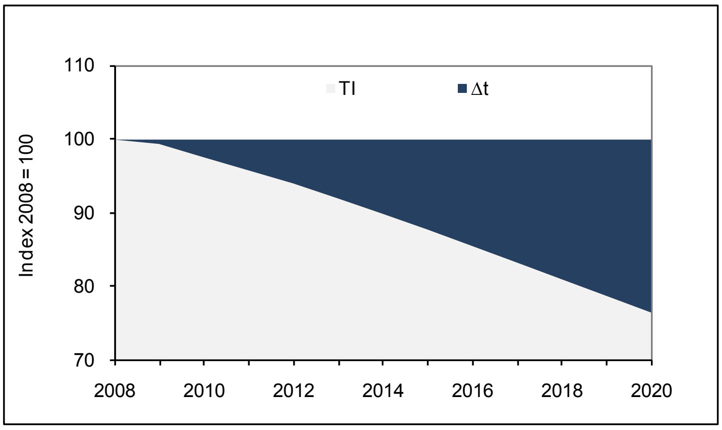
Table 7.25: Technology Wedge E-4: Summary of energy indicators

Reduction in heat and electricity output due to reduced demand	**2008** 2008=100	**2020/2008** %	**2020** 2008=100
Transformation Output (TO)	**100**	**-15**	**85**
Coal	100	-88	12
Oil	100	-79	21
Gas	100	-33	67
Transformation Input (TI)	**100**	**-23**	**77**
Coal	100	-92	8
Oil	100	-82	18
Gas	100	-43	57

Source: Statistics Austria (2009a), UNFCCC (2010); own calculations.

In Figure 7.23 changes in the index of transformation input until 2020 are depicted. The index values can be transformed into absolute changes in transformation input compared to 2008 and may also be compared to the reference scenario.

Figure 7.23: Technology Wedge E-4: Effects on transformation input[1]

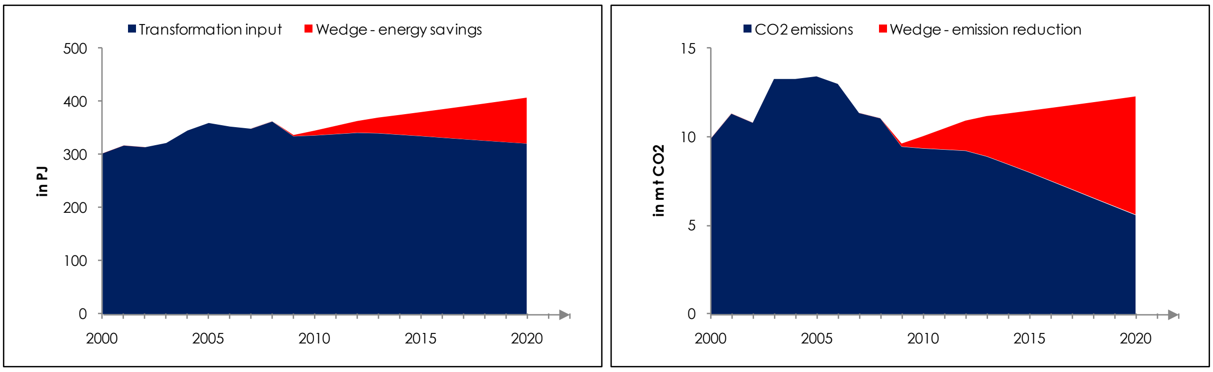


Source: Statistics Austria (2009a), UNFCCC (2010); own calculations. – [1] Δt describes the combined effect of changes in transformation output and transformation efficiency on transformation input. TI is transformation input.

Using emission factors by energy source (UNFCCC, 2010) and changes in absolute transformation input emission savings of Technology Wedge E-4 are calculated. Transformation input is reduced by 85 PJ compared to the EnergyTransition reference scenario. This reduction is equivalent to a reduction in CO_2 emissions of 7 million t.

Table 7.26 and Figure 7.24 summarise the effects of the implementation of Technology Wedge E-4 on transformation input and related CO_2 emissions.

Figure 7.24: Technology Wedge E-4: Effects on transformation input (left) and CO_2 emissions (right) in energy generation



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Table 7.26: Technology Wedge E-4: Effects on transformation input and related CO_2 emissions

Energy source	**Transformation input**				**CO2 emissions**			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in m t	in m t	Difference to Reference	
			in PJ	in %			in m t	in %
Fossil Fuels	**136**	**67**	**-85**	**-56.1**	**9.7**	**4.1**	**-6.7**	**-62.1**
Coal	47	8	-44	-84.6	4.6	0.8	-4.2	-84.6
Oil	9	3	-7	-69.7	0.7	0.2	-0.5	-69.7
Gas	80	56	-34	-38.2	4.4	3.1	-1.9	-38.2
Renewables	**227**	**255**	**0**	**0.0**	**1.3**	**1.5**	**0.0**	**0.0**
Wastes	13	15	0	0.0	1.3	1.5	0.0	0.0
Biofuels	69	78	0	0.0	0.0	0.0	0.0	
Hydro	137	150	0	0.0	0.0	0.0	0.0	
Wind	7	10	0	0.0	0.0	0.0	0.0	
PV	0	0	0	0.0	0.0	0.0	0.0	
Other	1	1	0	0.0	0.0	0.0	0.0	
Total	**363**	**322**	**-85**	**-20.9**	**11.0**	**5.6**	**-6.7**	**-54.5**

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

Economic data for investment and operating phase

Investment costs related to Technology Wedge E-4 appear in the energy consuming sectors, mobility, buildings and manufacturing. The investment effects in these sectors translate into lower transformation input for electricity and heat generation in the energy sector. This leads to a lower fuel input in the energy sector. This amounts to cost savings from reduced fuel input of 387 million € in 2020.

7.2.5 *Combination of technology wedges*

Most technology wedges have impacts on the potential of other technology wedge. Therefore the potential for combinations of different technology wedges has to be analysed. In WP4 technology wedges aiming at improving the efficiency of the transformation process and switching from fossil fuels to renewables or fuels with lower carbon intensity (technology wedges E-1 to E-3) can be combined without reducing each other's emission reduction potential. Moreover, as Technology Wedge E-1 which addresses the intensified use of wind power does not exploit the full wind power potential by 2020, this technology wedge may be employed twice yielding an emission reduction of 2 million t CO_2 in 2020. Tables 7.25 and 7.26 show the combined energy and emission savings of technology wedges E-1 to E-3 in 2020 compared to the EnergyTransition reference scenario. Total savings in transformation input amount to 23.6 PJ in 2020, total emission reductions are 4 million t CO_2.

Alternatively, however, combinations with Technology Wedge E-4 could be implemented instead of technology wedges E-1 to E-3. Technology Wedge E-4 analyses reductions in transformation input and related emissions due to reductions in electricity and heat demand in the energy using sectors (see Part B, chapters 4 to 6). In 2020 Technology Wedge E-4 reduces transformation input by 85 PJ and CO_2 emissions by 7 million t respectively (see chapter 7.2.3). Possible combinations could include a high share of Technology Wedge E-4 and only low shares of the other technology wedges or vice versa.

Table 7.27: Changes of transformation input for wedge combination in 2020 compared to reference scenario

Technology Wedge		Transformation Input Difference to Reference in PJ				
		Coal	Oil	Gas	Renewables	Total
E-1	Wind power	-15.19	0.00	-9.63	11.53	-13.29
E-2	Hydro power	-7.61	0.00	-4.82	5.77	-6.66
E-3	Biomass and biogas	-5.68	0.00	-8.22	10.23	-3.66
	Total	-28.48	0.00	-22.67	27.54	-23.61

Source: Statistics Austria (2009a, b); own calculations.

Table 7.28: Changes of CO_2 emissions for wedge combinations in 2020 compared to reference scenario

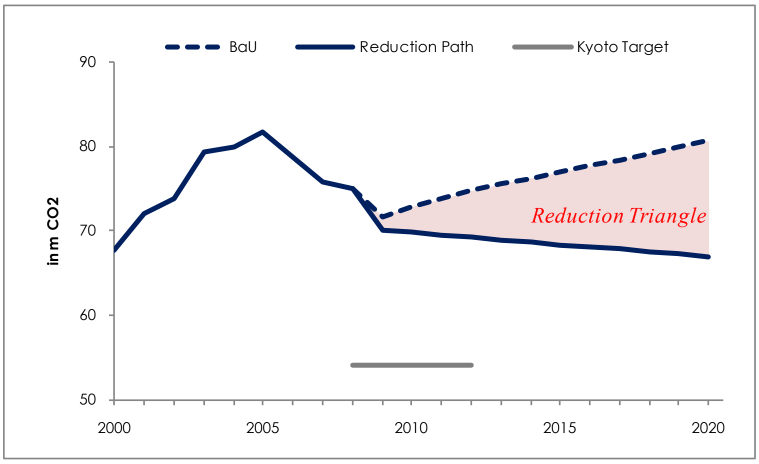
Technology Wedge		CO2 emissions 2020 Difference to Reference in million t				
		Coal	Oil	Gas	Renewables	Total
E-1	Wind power	-1.47	0.00	-0.53	0.00	-2.00
E-2	Hydro power	-0.74	0.00	-0.27	0.00	-1.00
E-3	Biomass and biogas	-0.55	0.00	-0.45	0.00	-1.00
	Total	-2.76	0.00	-1.25	0.00	-4.01

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

8 Feasible technology wedge combinations for the reduction triangle

According to the approach by Pacala and Socolow (2004) a reduction triangle for Austrian GHG emissions is defined in line with the EU Energy and Climate Package (European Commission, 2008a, 2008b). The reference scenario and the reduction path – which is derived from the 2020 targets of the EU Energy and Climate Package – define the emission reduction requirement until 2020, the so called "reduction triangle". The methodology for developing the reference scenario as well as assessing the development of final energy demand, electricity and heat generation and GHG emissions until 2020 is described in detail in Part B, chapter 2. The reduction requirements until 2020 compared to 2005 GHG emissions and the reference path yield the reduction triangle. This is illustrated in Figure 8.1. The reduction requirement to comply with the EU targets is 8 million t[50] CO_2 compared to 2008. As we can observe a reduction of CO_2 emissions between 2005 and 2008 the reduction requirement with respect to the base year 2005 of the EU Energy and Climate Package is 15 million t CO_2. The difference in CO_2 emissions between the reference scenario and the emission target in 2020 is estimated to amount to 14 million t CO_2.

Figure 8.1: Reduction triangle for Austria



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations. – The Kyoto target in this graph represents only the reduction requirements for CO_2 based on the assumption that the Austrian Kyoto target is equally distributed over all categories of greenhouse gases.

Technology wedges filling the reduction triangle can be grouped into two categories:

- "efficiency wedges" and
- "fuel shift wedges".

[50] According to the calculation of CO_2 emissions in the EnergyTransition project. Deviations from official emission data are quantified and described in Part B, chapter 2. The reduction requirement for CO_2 with respect to the base year 2005 in the EU Energy and Climate Package amounts to 15 million t CO_2. The significant difference in the reduction requirements with respect to 2005 and 2008 is the result of an overall decrease of CO_2 emissions of 6,7 million t between the two years.

"Efficiency wedges" are characterised by CO_2 savings resulting from lower final energy demand or from lower transformation input. Technology wedges achieving these reductions in energy consuming sectors (in this project: mobility, buildings and industry) can originate either by a reduction of (redundant) energy services or by a decline in useful energy intensity (useful energy by service) or final energy intensity (final energy by useful energy). For electricity and heat generation, efficiency wedges imply a reduction in transformation input through an improvement in transformation efficiency.

"Fuel shift wedges" describe CO_2 emission reductions resulting from a shift to fuels with lower carbon content, e.g. an intensified use of renewables or a substitution of coal and oil by gas. Technology wedges can either concentrate on one of the two options or represent a combination of both, for example if coal based electricity generation is substituted by biomass based cogeneration.

The reduction triangle shows a reduction requirement of 14 million t CO_2 in 2020 – the difference between the reference path and the reduction path in 2020 (see above and Part B, chapter 2.3). The catalogue of technology wedges based on the storylines developed for the areas mobility, buildings, industry and supply of heat and electricity reveals that the necessary emission reduction to meet the EU targets can only be achieved by applying both efficiency and fuel shift wedges. Given the uncertainty of the reference path – i.e. a potentially higher or lower effective reduction requirement in 2020 – it has to be emphasised that other combinations of technology wedges could also be implemented to comply with a higher/lower reduction target compared to the reference path.

Filling the reduction triangle can either have a stronger focus on "efficiency wedges" or on "fuel shift wedges". In the following we present two different technology wedge portfolios for filling the reduction triangle, one focusing primarily on energy efficiency and one focusing mainly on changes in the fuel mix. The economic implications for each portfolio are analysed in an input-output setting in Part B, chapter 9.

8.1 A technology wedge portfolio focusing on energy efficiency

This section presents a combination of technology wedges with a focus on energy efficiency. Hence, technology wedges from the areas mobility, buildings and manufacturing and their effects on the supply of electricity and heat (Technology Wedge E-4) are analysed. Table 8.1 presents the 18 technology wedges[51] considered to fill the reduction triangle and achieve an emission reduction of 14 million t CO_2 in 2020.

[51] The additivity of wedges is ensured.

Table 8.1: Technology wedge combination for the efficiency wedge portfolio

Technology wedge	
M-1	Promotion of efficient transport saving land use
M-2	Improvement of public transport
M-3	Extension of non-motorised transport
M-4	Alternative propulsion technologies
M-5	Freight transport
M-6	Efficiency increase by lightweight construction of vehicles
M-8	Relocation of fuel consumption
B-1	Thermal refurbishment of existing buildings
B-2	Construction of new buildings according to Passive House Standard
B-3a	Replacement of heating systems by more efficient systems based on renewables
B-3b	Solar heat for space heating and hot water preperation
B-4	Increased power production of buildings for own consumption
B-5	Energy optimised appliances, lighting and equipment
P-1	Energy demand for industrial buildings
P-2	Process intensification and process integration
P-3	Energy efficient engines
P-4	Combined heat and power
E-4	Reduction in electricity and heat generation through reduced demand

For mobility all technology wedges except M-7 (increased biofuel additions) are considered[52]. For the sector buildings all wedges are included, for manufacturing technology wedges focusing on fuel substitution, that is P-5, P-6 and P-7 (substitution of emission intensive fossil fuels by gas, solar thermal energy and biomass) are excluded. In order to ensure the additivity of the technology wedges the portfolio builds on the sector specific results for wedge combinations for mobility, buildings, industry and supply of electricity and heat, and considers only feasible combinations. From the sector electricity and heat supply only Technology Wedge E-4 – which analyses emission reductions due to reduced demand resulting from the other 17 wedges – is included in this technology wedge portfolio. All wedges address – at least partly – an increase in energy efficiency.

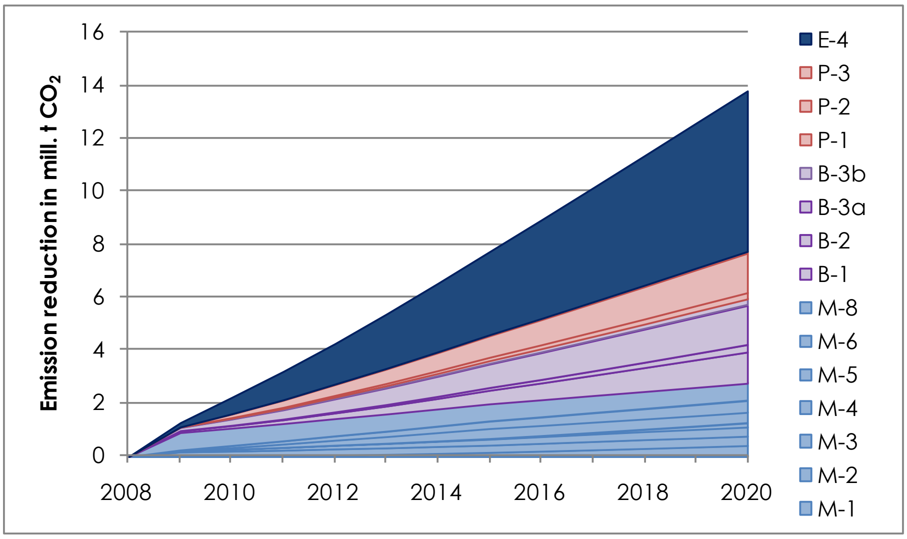
Figure 8.2 illustrates the contribution of each technology wedge to total emission reduction. Light blue wedges originate from the sector mobility, purple wedges refer to the building sector and red wedges to the manufacturing sector. The dark blue wedge refers to the sector electricity and heat supply. Technology wedges B-4 (PV), B-5 (efficient appliances) and P-4 (CHPs) are not attributed to the energy consumption of the sectors buildings and manufacturing, but are incorporated in the sector electricity and heat supply in form of a

[52] 17% of the emission reduction potential of Technology Wedge M-8 are necessary to reach the emission reduction requirement.

reduced demand for electricity and heat. Hence, the emission reductions resulting from these wedges are part of Technology Wedge E-4.

The change in energy demand in the areas mobility, buildings and manufacturing is shown in Table 8.2. For buildings and manufacturing electricity and heat demand is reduced in this technology wedge portfolio. For the transport sector electricity demand, however, increases due to a higher supply of public transport and a larger number of electric vehicles compared to the reference scenario. The increased number of electric vehicles is considered only as additional electricity demand. System effects regarding electricity storage or smoothing of load curves are left aside. Reduced electricity and heat consumption as well as the use of CHPs in the industry sector result in an emission reduction of 6 million t CO_2 (Table 8.2) that are accounted for in Technology Wedge E-4.

Figure 8.2: Emission reduction: Technology wedge portfolio focusing on energy efficiency



Source: Own calculations.

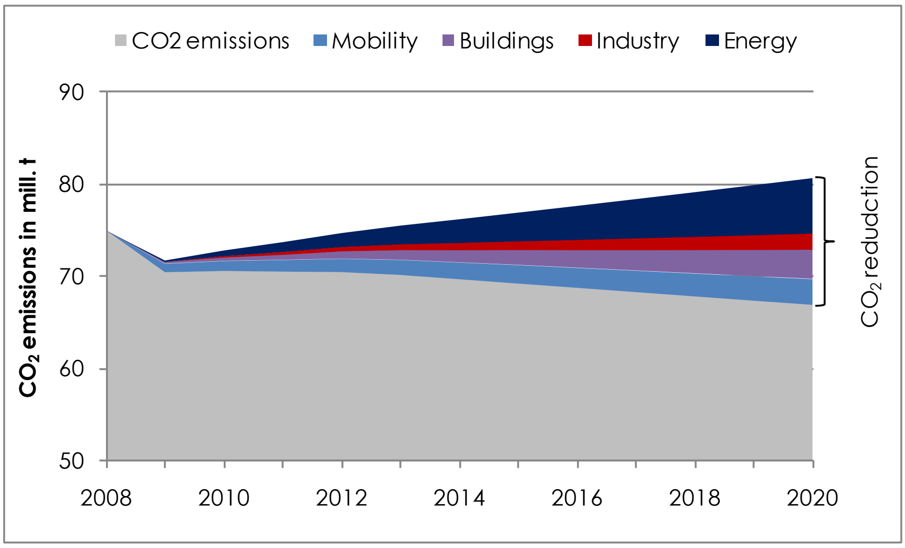
Table 8.2: Technology Wedge E-4: Changes in electricity and heat demand in the efficiency wedge portfolio

		Changes in final energy demand in 2020 Compared to reference			
		Electricity		Heat	
		in PJ	in %	in PJ	in %
WP1	Mobility	2.20	7		
WP2	Buildings	-12.47	-41	-4.48	-74
WP3	Industry	-19.93	-66	-1.54	-26
	Total	**-30.19**	**-100**	**-6.03**	**-100**

Source: Own calculations.

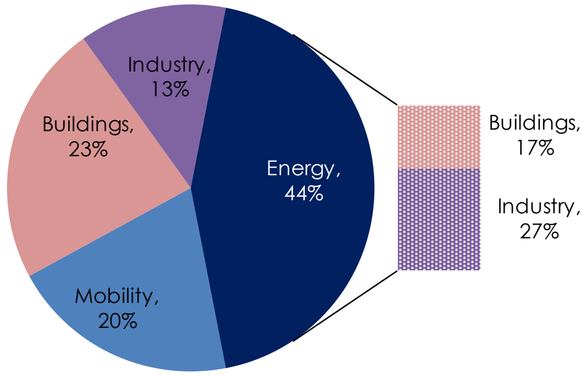
In Figure 8.3 the emission reductions from individual wedges are aggregated by sector and contrasted with the emission path of the reference scenario. Emission reductions from the mobility sector are 2.8 million t CO_2 in 2020. The technology wedges in the building sector achieve reductions of 3.2 million t CO_2 in 2020 compared to the EnergyTransition reference scenario. Emission reductions in the manufacturing sector amount to 1.8 million t in 2020 in this technology wedge portfolio. The largest emission reduction – 6 million t CO_2 in 2020 – is achieved by the energy sector. It has to be emphasised, however, that this emission reduction is exclusively the result of the lower heat and electricity demand resulting from the other sectors' efforts. A simple comparison of emission reductions by sector neglects this interrelationship of different levels in the energy cascade as explicitly considered in the project EnergyTransition (see Figure 8.4). The figure has to be interpreted as rough estimation. The emission effects from lower electricity and heat demand depend on the assumption which technologies and fuels are reduced for electricity and heat generation. Furthermore the additional electricity consumption in mobility (see Table 8.2) is neglected.

Figure 8.3: Technology wedge portfolio focusing on energy efficiency compared to reference scenario



Source: Own calculations.

Figure 8.4: Sectoral emission reduction shares in the efficiency portfolio in 2020



Source: Own calculations.

The overall effects of the energy efficiency portfolio focusing on energy flows and emission reductions by energy source are illustrated in Table 8.3. Energy flows from final energy consumption and from transformation input in 2020 are 200 PJ lower than in the reference path. Oil use is reduced by almost 80 PJ, gas by 63 PJ. Coal contributes 45 PJ which translates into a relative reduction of almost 50% compared to the reference path. By reducing final demand the energy efficiency portfolio has an effect on all energy sources, thus also energy flows from renewables are slightly lower (2.8%) than in the reference scenario. The change in renewable has no relevance for the emission reduction of 14 million t CO_2.

Table 8.3: Change in energy flows and emission reduction by energy source – energy efficiency portfolio

Energy source	**Final Energy Consumption and Transformation Input**				**CO2 emissions**			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	50.8	-45.4	-47.2	8.53	4.99	-4.4	-46.8
Oil	456.8	417.9	-79.2	-15.9	35.44	32.83	-5.7	-14.9
Gas	289.2	255.5	-63.2	-19.8	15.90	14.05	-3.5	-19.8
Renewables	380.5	418.6	-11.9	-2.8	2.87	3.13	0.0	0.0
Total	1,213.8	1,142.8	-199.6	-12.1	62.7	55.0	-13.6	-18.7

Source: Own calculations.

8.2 A technology wedge portfolio focusing on low carbon fuels

The combination of technology wedges presented in this section mainly includes technology options focusing on low carbon fuels. This means that primarily technology wedges addressing a fuel shift in energy supply or in energy demand are considered. In order to fill the reduction triangle, however, some technology wedges that focus exclusively on improvements in energy efficiency (technology wedges M-3, M-6, B-1) need to be included.

The list of technology wedges chosen is given in Table 8.4. In this combination all technology wedges for mobility are considered[53]. For the building sector four technology wedges – thermal refurbishment (B-1), new buildings in PHS (B-2), replacement of heating systems (B-3) and solar heating (B-4) – are regarded. The three options considered for the manufacturing sector in this technology wedge portfolio exclusively deal with shifting final energy demand towards low carbon fuels (P-5, P-6 and P-7). For the energy sector four technology wedges are included: Technology Wedge E-1 (‘wind power') achieving a reduction of 1 million t CO_2 is included twice thus contributing a CO_2 reduction of 2 million t. Technology wedges E-2 and E-3 (hydropower and bio-energy based CHPs) are also included in this combination. Technology Wedge E-4 again depicts lower final energy demand in the 18 technology wedges in the the sectors mobility, buildings and industry.

Table 8.4: Technology wedge combination used in the low carbon portfolio

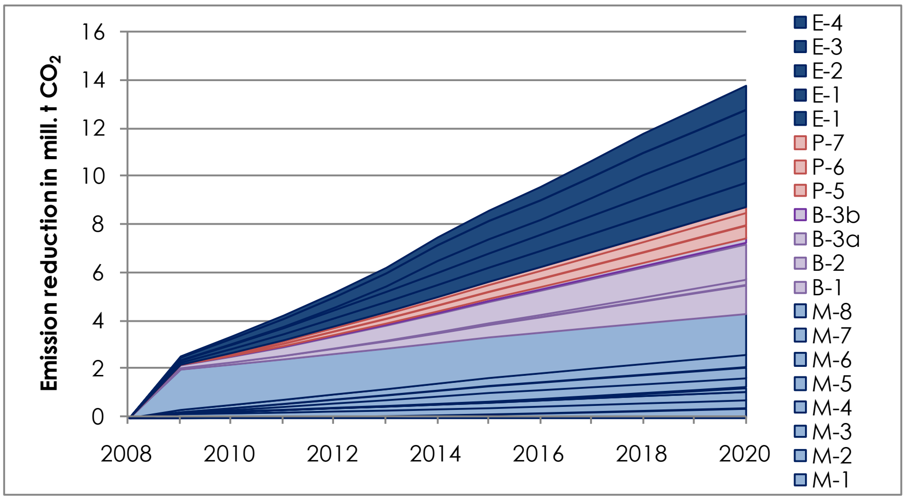
Technology wedge	
M-1	Promotion of efficient transport sav ing land use
M-2	Improv ement of public transport
M-3	Extension of non-motorised transport
M-4	Alternativ e propulsion technologies
M-5	Freight transport
M-6	Efficiency increase by lightweight construction of v ehicles
M-7	Increase of biofuel additions
M-8	Relocation of fuel consumption
B-1	Thermal refurbishment of existing buildings
B-2	Construction of new buildings according to Passiv e House Standard
B-3a	Replacement of heating systems by more efficient systems based on renewables
B-3b	Solar heat for space heating and hot water preperation
P-5	Substitution of fossil energy sources with high emission-coefficients
P-6	Biomass for process heat
P-7	Solar thermal energy for process-heat and space heating
E-1	Substitution of fossil electricity generation by wind power
E-2	Substitution of fossil electricity generation by run-of-riv er hydro plants
E-3	Substitution of fossil energy generation by biomass and biogas CHPs
E-4	Reduction in electricity and heat generation through reduced demand

The contribution of each technology wedge to the total emission reduction of 14 million t CO_2 in 2020 is illustrated in Figure 8.5. Light blue wedges again are part of the mobility sector; purple wedges are part of the building sector. Red wedges and dark blue wedges are from manufacturing and electricity and heat supply respectively. All wedges follow the diffusion

[53] 43% of the emission reduction of Technology Wedge M-8.

path described in the storylines. The emission reductions of the different wedges are, however, adjusted to reflect the feasible combination of the wedges in order to ensure the additivity of the wedges.

Figure 8.5: Emission reduction: Technology wedge portfolio focusing on low carbon fuels



Source: Own calculations.

Technology Wedge E-4 again results from reduced energy demand in the other 18 technology wedges included in this combination. The overall contribution of the sector buildings to a lower electricity and heat demand compared to the reference scenario is shown in Table 8.5. For the mobility sector electricity demand, however, increases due to higher levels of public transport and electric vehicles compared to the reference scenario. Fuel shift wedges for the manufacturing sector chosen for this portfolio do not affect electricity or heat consumption. Decreasing electricity and heat consumption results in an emission reduction of one million t CO_2 that is accounted for in Technology Wedge E-4.

Table 8.5: Technology Wedge E-4: Changes in electricity and heat demand in the low carbon triangle

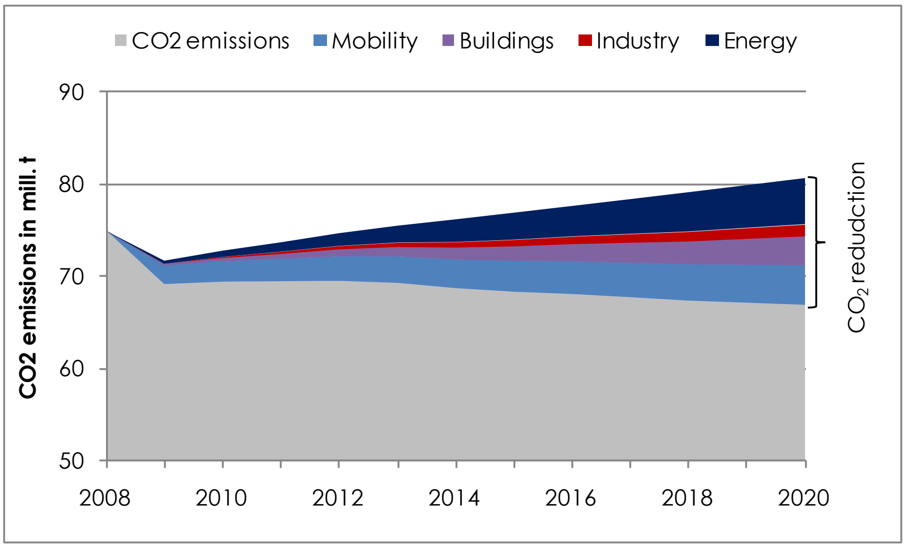
		Changes in final energy demand in 2020 Compared to reference			
		Electricity		Heat	
		in PJ	in %	in PJ	in %
WP1	Mobility	2.20	90		
WP2	Buildings	-4.66	-190	-4.48	-100
	Total	**-2.46**	**-100**	**-4.48**	**-100**

Source: Own calculations.

In Figure 8.6 the contribution of the sectors to fill the 14 million t reduction triangle is illustrated. In 2020 CO_2 emission from the mobility sector are reduced by 4.3 million t compared to the

EnergyTransition reference scenario. CO_2 emissions from buildings are 3.2 million t lower than the emissions in the reference scenario in 2020. The industry sector and the energy sector contribute CO_2 savings of 1.3 million t and 5 million t respectively. Compared to the energy efficiency portfolio of technology wedges, emission reductions are roughly the same in the sectors mobility and buildings. Emission reductions in the industry sector, however, are lower than in the efficiency portfolio while CO_2 reductions in the energy sector are higher due to the focus on fuel shift wedges instead of efficiency wedges.

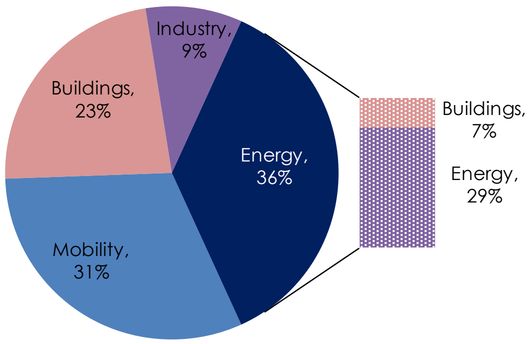
Figure 8.6: Technology wedge portfolio focusing on low carbon fuels compared to reference scenario



Source: Own calculations.

The emission reductions accounted for in the energy sector result from fuel switches and efficiency improvements in electricity and heat generation on the one hand and from energy savings in the building sector on the other hand. With respect to the latter, a simple comparison of emission reduction shares by sector neglects this interrelationship of different levels in the energy cascade as explicitly considered in the EnergyTransition project (Figure 8.7). As mentioned above the emission reduction has to be interpreted as rough estimate. The emission effects from lower electricity and heat demand depend on the assumption which technologies and fuels are reduced for electricity and heat generation.

Figure 8.7: Sectoral shares in emission reductions in the low carbon portfolio in 2020



Source: Own calculations.

Table 8.6 summarises the overall effects of the low carbon portfolio focusing on energy flows and emission reductions by energy source. Energy flows from final energy consumption and from transformation input in 2020 are 140 PJ lower than in the reference path. The low carbon portfolio thus yields lower changes in energy flows than the energy efficiency portfolio, although both portfolios achieve an emission reduction of 14 million t CO_2. Oil use is reduced by almost 100 PJ, gas by 47 PJ. Coal contributes approximately 40 PJ which is somewhat less than in the energy efficiency portfolio. The largest difference to the energy efficiency portfolio results for renewables, which showed a slight decrease in the efficiency portfolio compared to the reference path. In the low carbon portfolio energy flows from renewables exceed the reference scenario by 45 PJ (10%). Thus, in terms of producing not only emissions but also energy flows – irrespective of the energy sources – efficiency portfolios generate superior results.

Table 8.6: Change in energy flows and emission reduction by energy source – low carbon portfolio

Energy source	Final Energy Consumption and Transformation Input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	55.5	-40.6	-42.3	8.53	5.45	-3.9	-41.9
Oil	456.8	399.9	-97.3	-19.6	35.44	31.35	-7.2	-18.7
Gas	289.2	272.0	-46.7	-14.7	15.90	14.96	-2.6	-14.7
Renewables	380.5	475.7	45.2	10.5	2.87	3.13	0.0	0.0
Total	1,213.8	1,203.0	-139.4	-8.4	62.7	54.9	-13.7	-18.9

Source: Own calculations.

9 Economic analysis

The technology wedges approach as applied in the project EnergyTransition extends the original method by Pacala and Socolow (2004) by an economic analysis.

For the estimation of output and employment effects a multiplier analysis is conducted. These calculations show which demand effects follow from an investment activity in a certain sector. The multiplier analysis represents a static input-output approach using the input-output table by ÖNACE categories as published by Statistics Austria (2009c).

For the economic analysis investment and operating costs for each technology wedge were compiled in a bottom up approach. The economic analysis within the project EnergyTransition comprises on the one hand economic effects of the investment phase for two technology wedge portfolios based on an input output analysis. This is complemented by an illustration of the development of operating costs. On the other hand, for selected technology wedges a microeconomic cost appraisal is conducted[54] that – contrary to the macro perspective of the input output analysis – puts the focus on micro economic aspects.

9.1 Input output analysis: Employment and output effects of technology wedge portfolios

In this section the results of the input output analysis for the two portfolios of technology wedges described in Part B, chapter 8 are presented. The first technology wedge portfolio focuses on energy efficiency, while the second portfolio concentrates on fuel shifts towards low carbon fuels.

For the period until 2020 annual investment requirements for each technology wedge are compiled in a bottom up approach. Total investment costs as well as additional investment costs are assessed[55]. Additional investment costs apply to cost differences compared to a respective reference technology. In order to assess the domestic economic implications of the implementation of technology wedges, investment costs are split up into sectoral investment shares. The diffusion of technologies over time is defined by the storylines and can follow different paths: linear, exponential, stepwise or other.

For each of the two combinations of technology wedges considered, the input-output analysis is based on the additional investment costs of the technology wedges included in the portfolio. The use of additional investment costs ensures that the effects induced by a transformation of the energy system along the energy cascade are quantified. That is, only the employment and output effects of the technology wedges that go beyond investments required for a reference technology or a reference path are calculated. As in terms of

[54] The micro economic cost analysis can be found in the respective chapters on technology wedges for mobility, buildings, industry and supply of electricity and heat.

[55] For some technology wedges the assessment of investment cost was not possible and thus not all technology wedges could be considered for the quantification of the output and employment effects.

emission reductions for the portfolios only the combined wedges' reduction potential is taken into account. For the economic impacts, correspondingly, only the additional effort for transforming the energy system towards increased sustainability is considered. The assessment of the employment and output effects is based on an average annual investment for the period 2009 to 2020 as well as for investment in 2020.

9.1.1 *Economic effects of the wedge portfolio focusing on energy efficiency*

The first technology wedge portfolio focuses on energy efficiency measures to curb CO_2 emissions, as described in Part B, chapter 8. Hence, technology wedges in the areas mobility, buildings and manufacturing and their effects on the energy sector (Technology Wedge E-4) are analysed. Technology wedges chosen for the efficiency portfolio are listed in Table 9.1, showing the additional investment costs required for each wedge on average over the twelve-year period from 2009 to 2020 as well as in 2020.

The additional investment costs follow the diffusion path of the technologies described in the storylines and are based on the feasible combination of technology wedges in the sectoral analysis to ensure the additivity of the wedges. The highest share in additional investment costs accrues to the building sector (see also Table 9.1 below).

Table 9.1: Technology wedges and additional investment in the energy efficiency portfolio

Technology wedge		Additional investment		
		Average 2009/2020		2020
		in million €	in %	in million €
M-1	Promotion of efficient transport sav ing land use	48,1	0,8	48,1
M-2	Improv ement of public transport	834,9	13,3	834,9
M-3	Extension of non-motorised transport	45,0	0,7	45,0
M-4	Alternativ e propulsion technologies	191,3	3,0	582,9
M-5	Freight transport	33,0	0,5	33,0
M-6	Efficiency increase by lightweight construction of v ehicles	n.a.	n.a.	n.a
M-8	Relocation of fuel consumption	n.a.	n.a.	n.a
B-1	Thermal refurbishment of existing buildings	3.248,8	51,8	4.826,0
B-2	Construction of new buildings according to Passiv e House Standard	621,4	9,9	1.085,7
B-3a	Replacement of heating systems by more efficient systems	144,7	2,3	188,9
B-3b	Solar heat for space heating and hot water preperation	667,8	10,6	541,2
B-4	Increased power production of buildings for own consumption	43,7	0,7	70,2
B-5	Energy optimised appliances, lighting and equipment	0,0	0,0	0,0
P-1	Energy demand for industrial buildings	131,5	2,1	143,4
P-2	Process intensification and process integration	184,8	2,9	201,6
P-3	Energy efficient engines	51,0	0,8	55,7
P-4	Combined heat and power	26,0	0,4	28,4
E-4	Reduction in electricity and heat generation through reduced demand	0,0	0,0	0,0
Total		**6.271,9**	**100,0**	**8.685,1**

Source: Own calculations.

Additional costs for the six technology wedges in the area buildings amount to 6,712 million € in 2020; average annual investment costs of these technology wedges for the period 2009 to 2020 are 4,726 million € respectively. Technology wedges for mobility have the second largest share in total additional investment costs amounting to 1,544 million € in 2020 and to an average of 1,152 million € p.a. for the period 2009 to 2020 respectively. Additional investments for the four technology wedges in manufacturing are 429 million € in 2020 and on average 393 million € p.a. over the twelve years respectively. For energy supply only Technology Wedge E-4 which comprises emission savings due to reduced final energy demand is considered in this technology wedge portfolio. For this technology wedge investment costs are zero as all investment costs are accounted for in the areas mobility, buildings and manufacturing.

Table 9.2 shows the sectoral disaggregation of total additional investment for the technology wedge portfolio focusing on energy efficiency. The largest share in additional investment accrues to construction work (51% both in 2020 and on average over the period 2009 to 2020). Other sectors that are positively affected are the sector chemicals and chemical products (10% of investment in 2020 and on average 9% over the twelve-year period) and the sector other rubber and plastic products (8% of investment in 2020 and 9% on average over the twelve-year period).

Table 9.2: Sectoral disaggregation of additional investment in the energy efficiency portfolio

Sector	Additional investment		
	Average 2009/2020		2020
	in milllion €	in %	in milllion €
Construction work	3,228.0	51.5	4,440.8
Fabricated metal products, except machinery and equipment	308.0	4.9	303.7
Printed matter and recorded media	180.5	2.9	180.5
Radio, telev ision and communication equipment and apparatus	1.4	0.0	1.4
Other business serv ices	141.1	2.2	191.1
Electrical machinery and apparatus n.e.c.	46.1	0.7	112.2
Trade, maintenance and repair serv ices of motor v ehicles etc.	151.6	2.4	462.0
Machinery and equipment n.e.c.	82.3	1.3	89.6
Motor v ehicles, trailers and semi-trailers	2.9	0.0	2.9
Other transport equipment	190.0	3.0	190.0
Computer and related serv ices	1.4	0.0	1.4
Wood&wood prod.	193.5	3.1	295.6
Chemicals, chem. prod,	580.5	9.3	886.8
Rubber&plastic prod.	553.4	8.8	652.0
Other non-metallic prod.	394.9	6.3	602.5
Basic metals	133.7	2.1	196.5
Precision instruments	82.7	1.3	76.3
Total	**6,271.9**	**100.0**	**8,685.1**

Source: Own calculations.

The economic effects of implementing the technology wedges are summarised in Table 9.3. On average over the period 2009 to 2020, the efficiency portfolio generates output effects of 9,498 million € and value added effects of 4,633 million €. In terms of employment 80,469 jobs and 76,129 full time equivalents (FTE) are related to the implementation of this technology wedge portfolio. The output multiplier and the value added multiplier for the efficiency portfolio are 1.51 and 0.74 respectively. This means that with each million € of additional investment output increases by 1.51 million €, value added increases by 0.74 million €, which is related to the protection or creation of approximately 13 jobs.

In 2020 output effects of 14,115 million € and value added effects of 5,955 million € are generated. Employment effects are 106,932 jobs or 99,512 FTE respectively. The higher output and employment effects compared to the twelve-year average mainly result from the higher additional investment costs in 2020.

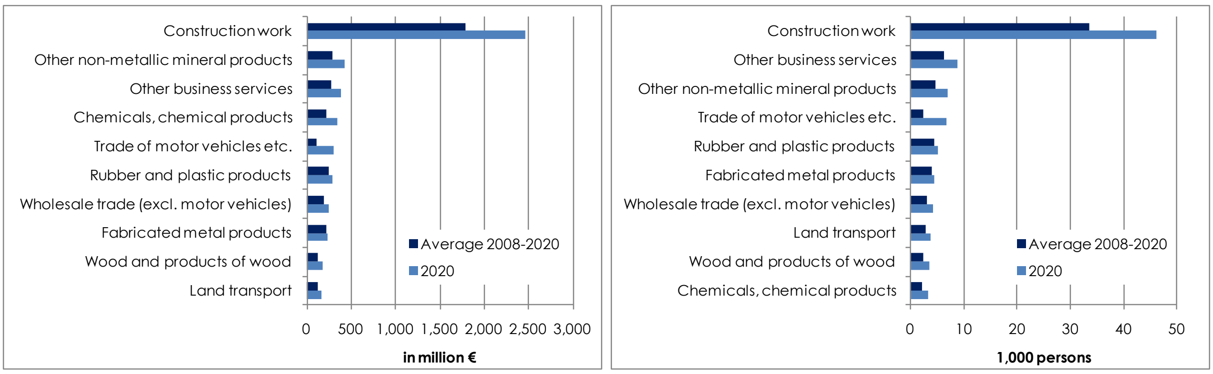
Table 9.3: Economic effects of the energy efficiency portfolio

		Average	2020
Output effects	mill. €	9,498	14,115
Value added effects	mill. €	4,633	5,955
Employment effcts	persons	80,469	106,932
	FTE [1]	76,129	99,512

Source: Own calculations. – [1] FTE stands for full time equivalents.

Figure 9.1 shows the sectoral effects of additional investment in the efficiency portfolio. Due to the large share in total additional investment the highest sectoral effects are found in the sector construction work. In addition, high value added effects can be observed for other non-metallic minerals, chemicals and chemical products and for other business services. Besides the employment effects in construction work, high employment effects result for the sectors other business services and for other non-metallic minerals.

Figure 9.1: Highest sectoral value added effects (left) and highest sectoral employment effects (right) in the efficiency portfolio



Source: Own calculations.

9.1.2 *Economic effects of the technology wedge portfolio focusing on low carbon fuels*

This portfolio of technology wedges focuses on shifting fuel consumption towards low carbon energy sources, as described in Part B, chapter 8. The list of technology wedges chosen in the portfolio is given in Table 9.4, including the additional investment costs required for each wedge on average over the twelve-year period from 2009 to 2020 and in 2020. The additional investment costs follow the diffusion path of the technologies described in the storylines and are based on the feasible combination of technology wedges in the sectoral analysis to ensure the additivity of the wedges.

The highest additional investment occurs again in the building sector. Additional costs for thermal refurbishment, new construction and replacement of heating systems total to 6,642 million € in 2020; average annual costs of the technology wedges for buildings for the period 2009 to 2020 are 4,683 million € respectively. Technology wedges for mobility have the second largest share in total additional investment (1,543 million € in 2020 and 1,152 million € p.a. on average). For lightweight construction (Technology Wedge M-6) it is assumed that no additional investment costs accrue, as it is assumed that the retail price for conventional and lightweight vehicles is the same; for increased biofuel additions (Technology Wedge M-7) additional investment costs cannot be quantified. The technology wedges for electricity and heat generation[56] have additional investment costs of 301 million € in 2020 and on average of 310 million € p.a. for the period 2009 to 2020. Additional investment for the three manufacturing technology wedges amounts to 143 million € in 2020 and on average to 131 million € p.a. over the twelve years respectively.

[56] In this portfolio of technology wedges, Technology Wedge E-1 ('wind power') is implemented twice.

Table 9.4: Technology wedges and additional investment costs in the low carbon portfolio

	Technology wedge	Additional investment		
		Average 2009/2020		2020
		in million €	in %	in million €
M-1	Promotion of efficient transport sav ing land use	48,1	0,8	48,1
M-2	Improv ement of public transport	834,9	13,3	834,9
M-3	Extension of non-motorised transport	45,0	0,7	45,0
M-4	Alternativ e propulsion technologies	191,3	3,0	582,9
M-5	Freight transport	33,0	0,5	33,0
M-6	Efficiency increase by lightweight construction of v ehicles	n.a.	n.a.	n.a.
M-7	Increase of biofuel additions	n.a.	n.a.	n.a.
M-8	Relocation of fuel consumption	n.a.	n.a.	n.a.
B-1	Thermal refurbishment of existing buildings	3.248,8	51,8	4.826,0
B-2	Construction of new buildings according to Passiv e House Standard	621,4	9,9	1.085,7
B-3a	Replacement of heating systems	144,7	2,3	188,9
B-3b	Solar heating	667,8	10,6	541,2
P-5	Substitution of fossil energy sources with high emission-coefficients	3,6	0,1	3,9
P-6	Biomass for process heat	24,8	0,4	27,1
P-7	Solar thermal energy for process-heat and space heating	103,0	1,6	112,3
E-1	Substitution of fossil electricity generation by wind power	160,6	2,6	160,6
E-2	Substitution of fossil electricity generation by run-of-riv er hydro plants	87,9	1,4	75,0
E-3	Substitution of fossil energy generation by biomass and biogas CHPs	61,5	1,0	65,5
E-4	Reduction in electricity and heat generation through reduced demand	0,0	0,0	0,0
	Total	**6.276,3**	**100,0**	**8.630,2**

Source: Own calculations. – Investment costs for Technology Wedge E-1 are given for two technology wedges as this wedge is implemented twice in this portfolio.

Table 9.5 gives the sectoral disaggregation of total additional investment for the low carbon technology wedge portfolio. Sectors most positively affected by the additional investment are construction work (50% both in 2020 and on average over the twelve-year period), the sector chemicals and chemical products (10% of total additional investment in 2020 and 9% on average over the twelve-year period) as well as the sectors rubber and plastic products and other non-metallic products.

Table 9.5: Sectoral disaggregation of additional investment for the low carbon portfolio

Sector	Additional investment		
	Average 2009/2020		2020
	in million €	in %	in million €
Construction work	3,118.8	49.7	4,303.0
Fabricated metal products, except machinery and equipment	303.7	4.8	296.7
Printed matter and recorded media	180.5	2.9	180.5
Radio, television and communication equipment and apparatus	1.4	0.0	1.4
Other business services	123.0	2.0	170.9
Electrical machinery and apparatus n.e.c.	153.6	2.4	207.8
Trade, maintenance and repair services of motor vehicles etc.	151.6	2.4	462.0
Machinery and equipment n.e.c.	118.4	1.9	119.8
Motor vehicles, trailers and semi-trailers	9.0	0.1	9.4
Other transport equipment	190.0	3.0	190.0
Computer and related services	1.4	0.0	1.4
Wood&wood prod.	193.5	3.1	295.6
Chemicals, chem. prod,	580.5	9.2	886.8
Rubber&plastic prod.	548.1	8.7	643.5
Other non-metallic prod.	391.4	6.2	596.8
Basic metals	127.5	2.0	189.8
Precision instruments	79.2	1.3	70.0
Land transport; transport via pipeline services	4.8	0.1	4.8
Total	**6,276.3**	**100.0**	**8,630.2**

Source: Own calculations.

The economic effects of implementing the technology wedge portfolio are shown in Table 9.6. On average over the period 2009 to 2020, the combination of technology wedges generates output effects of 9,500 million € and value added effects of 4,614 million €. The corresponding employment effects are 79,968 jobs and 75,669 full time equivalents (FTE) respectively. The output multiplier for this portfolio of technology wedges is hence 1.51, the value added multiplier is 0.74. This means that with each million € of additional investment output increases by 1.51 million €, value added increases by 0.74 million € and 13 jobs are created or protected.

In 2020 the low carbon technology wedge portfolio generates output effects of 13,068 million € and value added effects of 6,386 million €. Employment effects correspond to 111,073 jobs or 104,930 FTE. The higher economic effects compared to the twelve-year average result from the higher additional investment in 2020.

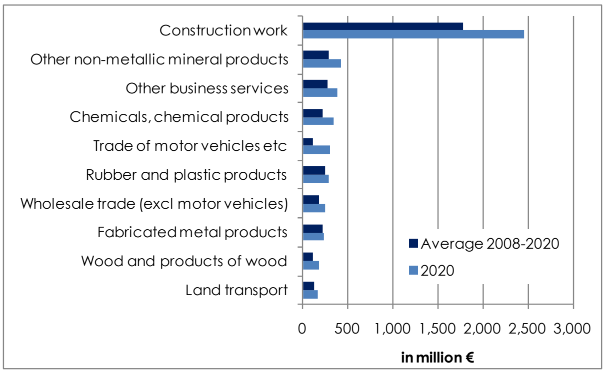
Table 9.6: Economic effects of the low carbon portfolio

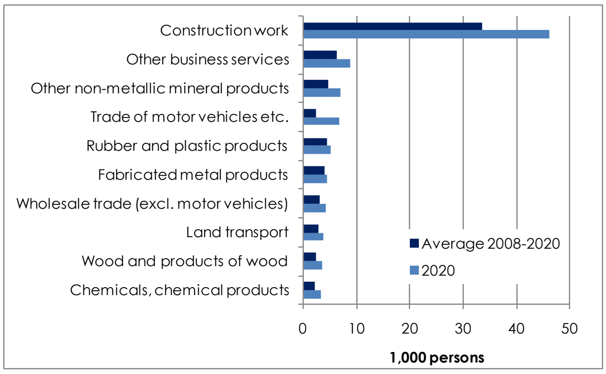
		Average	2020
Output effects	mill. €	9,500	13,068
Value added effects	mill. €	4,614	6,386
Employment effcts	persons	79,968	111,073
	FTE [1]	75,669	104,930

Source: Own calculations. – [1] FTE stands for full time equivalents.

As the largest economic stimulus from additional investment is found in the sector construction work as depicted in Table 9.5, value added effects and employment effects are also highest in this sector. Other sectors positively affected with respect to value added and employment are other non-metallic minerals, chemicals and chemical products as well as for other business services (see Figure 9.2).

Figure 9.2: Highest sectoral value added effects (left) and highest sectoral employment effects (right) in the low carbon portfolio





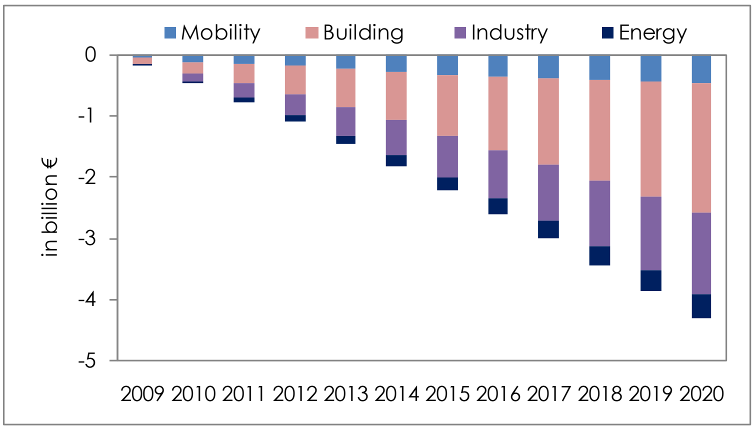
Source: Own calculations.

9.2 Operating costs in the technology wedge portfolios

The implementation of the two technology wedge portfolios described above has also considerable effects in the operating phase. In order to illustrate the difference in operating costs between the technology wedges and respective reference technologies a similar approach is followed as for the investment phase: Total operating costs of the technology wedges are contrasted with respective additional operating costs in order to illustrate the effect of the technology wedge. Negative additional operating costs hence refer to cost savings compared to a reference technology. In contrast to annual investment, operating costs as well as cost savings increase over time in line with the diffusion path of the investment and are thus cumulative.

Figure 9.3 illustrates the development of operating cost savings for the energy efficiency portfolio. Cost savings are quantified for the areas mobility, buildings, manufacturing and electricity and heat supply[57]. In line with the large contribution of the building sector to investments and emission reductions in this portfolio operating cost savings are highest in the building sector reflecting the significant energy savings. Figure 9.3 clearly illustrates the cumulative character of the operating cost effect. In 2020 operating cost savings amount to -4.3 billion €.

Figure 9.3: Operating cost savings of the energy efficiency portfolio



Source: Own calculations.

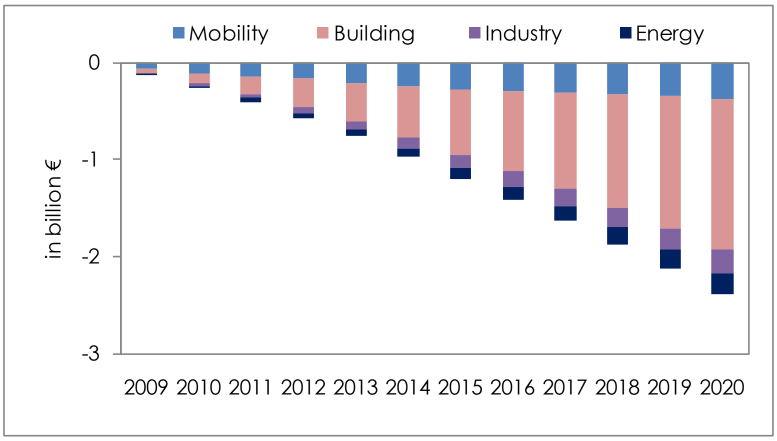
In general technology wedges realise operating cost savings compared to the respective reference technologies. A simple comparison between technology wedges with respect to the extent of cost savings, however, is not sensible as the simple focus on operating costs neglects the capital costs of the technology wedges and related relevant parameters like the service life of the technologies[58]. This perspective would be insufficient to comprehensively assess technological options as the focus on investment costs and payback times without accounting for effects over the whole service life.

A similar analysis is conducted for the technology wedge portfolio focusing on low carbon options. A comparison of the operating costs of the two technology wedge portfolios suggests that the energy efficiency combination yields considerably higher cost savings in 2020. The pronounced differences in operating costs between the two technology portfolios are not mirrored in the respective investment requirements.

[57] For some technology wedges a quantification of operating cost savings was not possible.

[58] A separate analysis for a sample of technology wedges implements these aspects in a microeconomic cost appraisal.

Figure 9.4: Operating cost savings of the low carbon portfolio



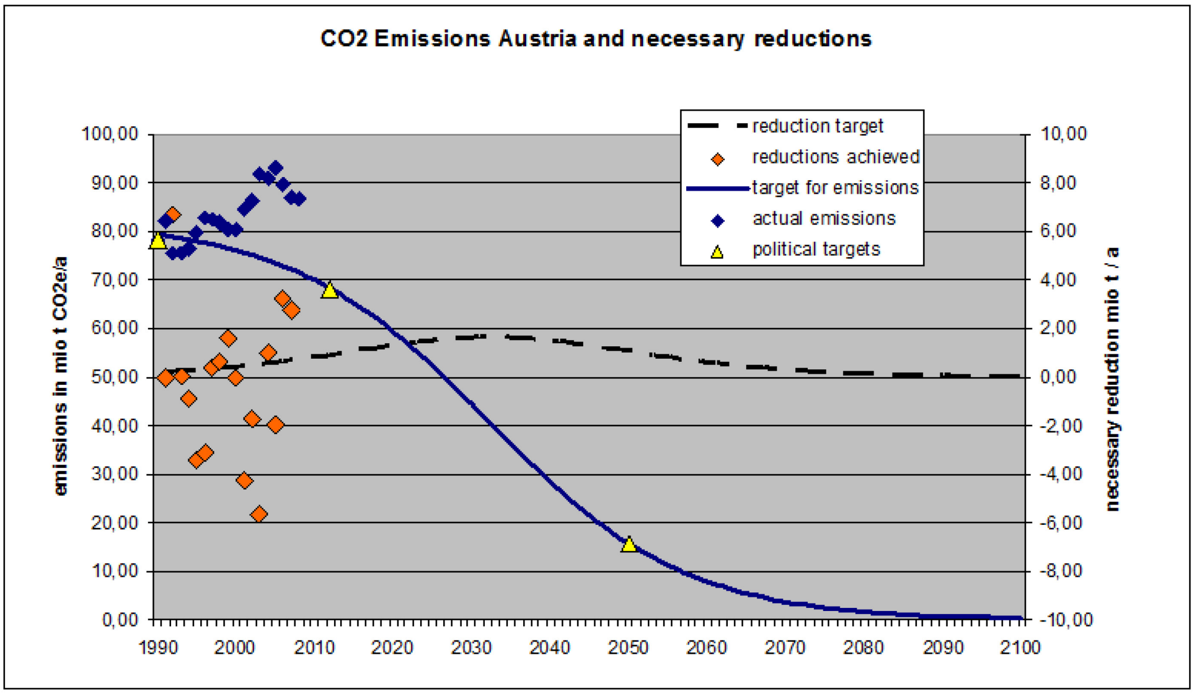
Source: Own calculations.

10 Perspectives for 2050

The long term GHG reduction target in order to limit the risk of a global temperature increase of more than 2°C requires a further scaling up of the measures and technologies as described in the storylines as well as continuous technological and social innovations. In the following long term perspectives until 2050 are set out that connect to the detailed analysis of emission reduction options until 2020 in the areas mobility, buildings, manufacturing as well as electricity and heat supply.

Scientific research findings on climate change and, more than this, statements of leading politicians and EU bodies demand a further reduction of greenhouse gas emissions beyond 2020. In July 2009 the leaders of the European Union and the G8 announced an objective to reduce greenhouse gas emissions by at least 80% below 1990 levels by 2050. In October 2009 the European Council set the appropriate abatement objective for Europe and other developed economies at 80-95% below 1990 levels by 2050 (see e.g. G8, Roadmap 2050). This ambitious target needs to be translated into a low carbon society with all its social and technological implications.

Figure 10.1: Emission reduction path till 2050 for Austria



Source: Own calculations.

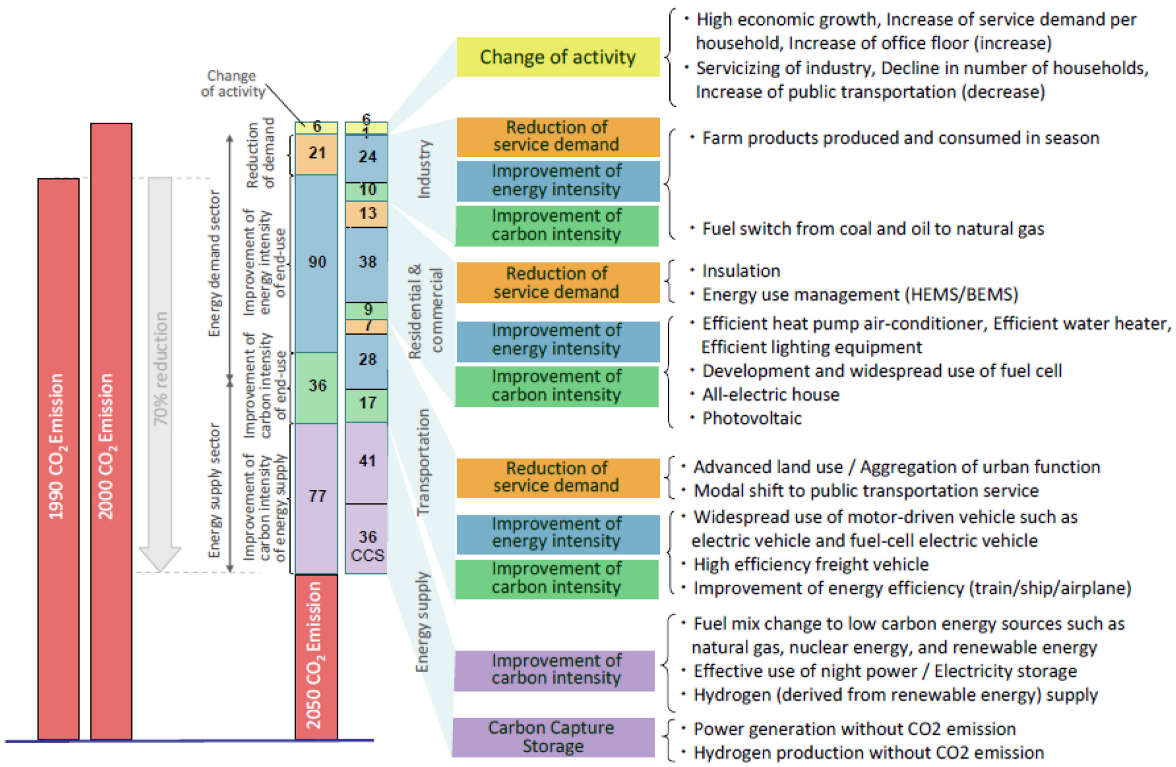
It can be assumed that the transition to the new low-carbon system will follow an S-shaped curve like any market penetration of new technologies. Figure 10.1 shows that the reduction goals for 2012 (-13% with the base year 1990 for Austria) and 2090 (-80%) are exactly in line with such a course (left axis). The highest annual reductions of about 1.64 million t CO_{2e} will be necessary in 2033 (dashed line, right axis). After 2040 the potential for further emission reductions is declining. As can be seen from the orange rectangles in the graph, actual reduction rates in the recent years were mostly below zero between 1990 and 2008, with only few exceptions. No clear development or steady reduction path as a result of systematic policy measures and regulation can be distinguished, however. The observable increase in emissions since the base year 1990 demands from Austria to put more emphasis on effective reduction measures.

Several countries already developed plans for a transition to a low carbon society (e.g. UK and Japan). Figure 10.2 illustrates how a 70% reduction goal should be achieved in Japan (NIES, 2008). This study contains quantitative roadmaps for introducing countermeasures and policies for reducing CO_2 emissions by 70% until 2050 compared to the 1990 level in Japan. It analyses the roadmaps with regard to the objective of reducing CO_2 emissions by 70%, minimising the total cost from 2000 to 2050 while satisfying the future service demand assumed in two scenarios. A list of 600 options (around 400 technological countermeasures and 220 policies) was prepared. The period necessary for implementation and the expected costs were assessed based on literature reviews, expert judgments, and market surveys. For all sectors the analysis follows three guidelines:

- reduction of service demand,
- improvement of energy intensity,
- improvement of carbon intensity.

Figure 10.2 illustrates the sectoral contribution (including a small share from CCS) of the three guiding principles in order to achieve the 70% emission reduction goal.

Figure 10.2: Strategy for a 70% reduction of CO_2 emissions in Japan until 2050



Source: National Institute for Environmental Studies (2008).

10.1 Perspectives for 2050 – Mobility

With the long term goals of GHG reduction particularly more stringent than the 2020 goals – the EU for example has repeatedly reaffirmed its GHG emission reduction objective of 80% to 95% by 2050 compared to 1990 levels[59] – emissions from mobility represent are particularly crucial for achieving that objective. Transport sector GHG emissions over the last decades have increased in Austria most strongly in both absolute and relative terms, compared to all Austrian sectors. With the shares of emissions e.g. of manufacturing roughly stable or even declining, transport is responsible for already more than a quarter of GHG emissions in Austria by 2008, a share that has steadily increased to date.

Any transport outlook up to 2050 has to be regarded with caution. Skinner et al. (2010) categorised the two main challenges in this respect:

[59] The European Commission has agreed on the objective to limit global warming to 2°C (European Commission, 2007), an objective that was later adopted within the Copenhagen Accord as well. Various documents agreed upon within the European Union clarify that the 2°Cobjective can only be achieved when the industrialised countries succeed in reducing their emissions by 80 to 95% by 2050: see Council of the European Commission (2010) and European Commission (2010), most recently.

"There are particular challenges associated with a project that is attempting to look 40 years into the future. First, it is difficult to know whether the transport vehicles and services of 2050 will be similar to, or distinctly different from, those of 2010. Second, as transport is largely a derived demand, which is determined by wider societal and economic developments, the society and economy of 2050 will be an important element in determining transport demand in 2050."

With this caveats in mind, we nevertheless seek to explore the potential transport sector development in Austria for the 2050 time horizon. We do find that the exploitation of the technology wedges for mobility set forth in chapter 4 does remain crucial also in the longer-term 2050 horizon, albeit with different relative weights attached to them. Even more so, the earlier we implement these wedges and thus avoid or escape from lock-ins in carbon-intensive structures, the better we can achieve the strict long-term emission reduction goals.

On the demand side for passenger transport the core drivers are likely to develop quite differently. One of the major drivers of passenger transport – population growth – is likely to level off, albeit in creating a different age structure (the 60+ generation increasing from a share of less than a quarter in 2008 to more than a third in 2050; see Table 10.1). With a larger fraction of elder population broadly equipped with a driving licence, the growth in motorised individual transport still might not level off as quickly as population growth does. Daily travel times have been rather stable in passenger transport over the last decades (at somewhat below one hour per day), and in connection to ever faster means of transport the average mileage per person has thus increased. Most studies consider daily travel time to be at a saturation point, while some take people to be prepared to travel up to seventy minutes per day.

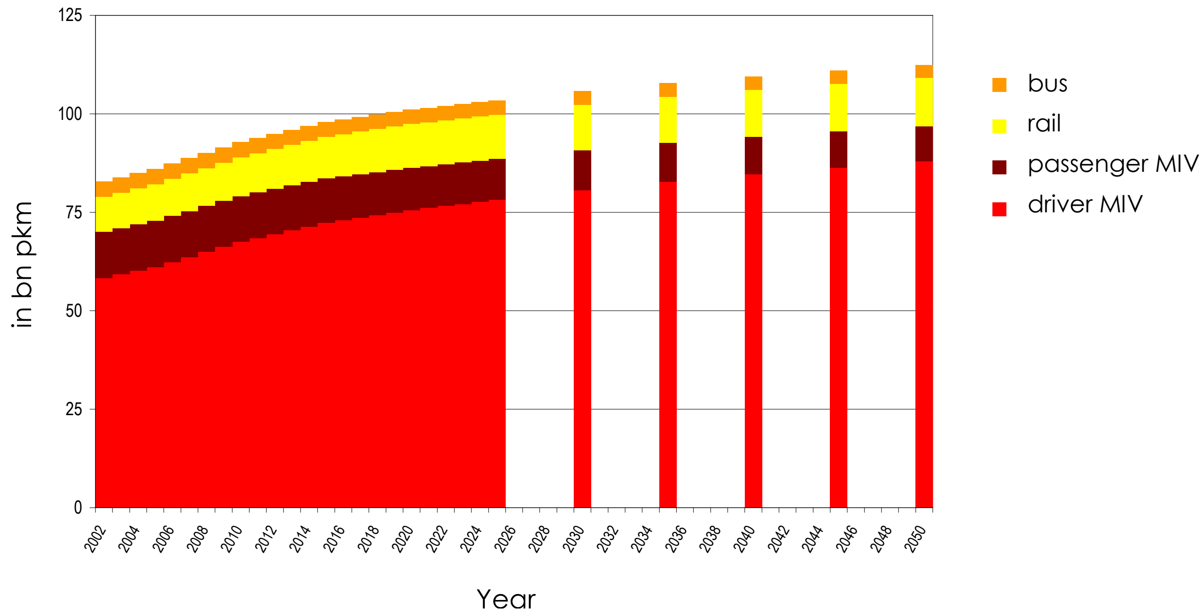
Table 10.1: Population forecast for Austria

Year	Population structure						
	Total	0-14 years	15 - 59 years	60 and more years	0-14 years	15 - 59 years	60 and more
	absolut				in %		
2008	8,336,549	1,269,556	5,186,511	1,880,482	15.2	62.2	22.6
2009	8,368,842	1,255,295	5,202,396	1,911,151	15.0	62.2	22.8
2010	8,396,760	1,244,170	5,214,699	1,937,891	14.8	62.1	23.1
2011	8,427,431	1,234,660	5,230,619	1,962,152	14.7	62.1	23.3
2012	8,462,046	1,227,682	5,247,771	1,986,593	14.5	62.0	23.5
2013	8,498,651	1,224,733	5,261,016	2,012,902	14.4	61.9	23.7
2014	8,535,845	1,225,142	5,270,316	2,040,387	14.4	61.7	23.9
2015	8,574,121	1,227,413	5,275,600	2,071,108	14.3	61.5	24.2
2020	8,748,917	1,245,284	5,223,688	2,279,945	14.2	59.7	26.1
2025	8,903,569	1,268,127	5,079,259	2,556,183	14.2	57.0	28.7
2030	9,048,365	1,282,698	4,958,051	2,807,616	14.2	54.8	31.0
2035	9,174,298	1,279,720	4,938,846	2,955,732	13.9	53.8	32.2
2040	9,287,466	1,268,918	4,969,513	3,049,035	13.7	53.5	32.8
2045	9,386,774	1,263,021	4,966,532	3,157,221	13.5	52.9	33.6
2050	9,467,172	1,268,536	4,962,088	3,236,548	13.4	52.4	34.2
2075	9,567,587	1,298,244	5,038,823	3,230,520	13.6	52.7	33.8

Source: Statistics Austria (2009d).

Using the main scenario of the population forecast together with stable trends – however at lower levels – for the other main drivers, one can derive a development for passenger transport as given in Figure 10.3.

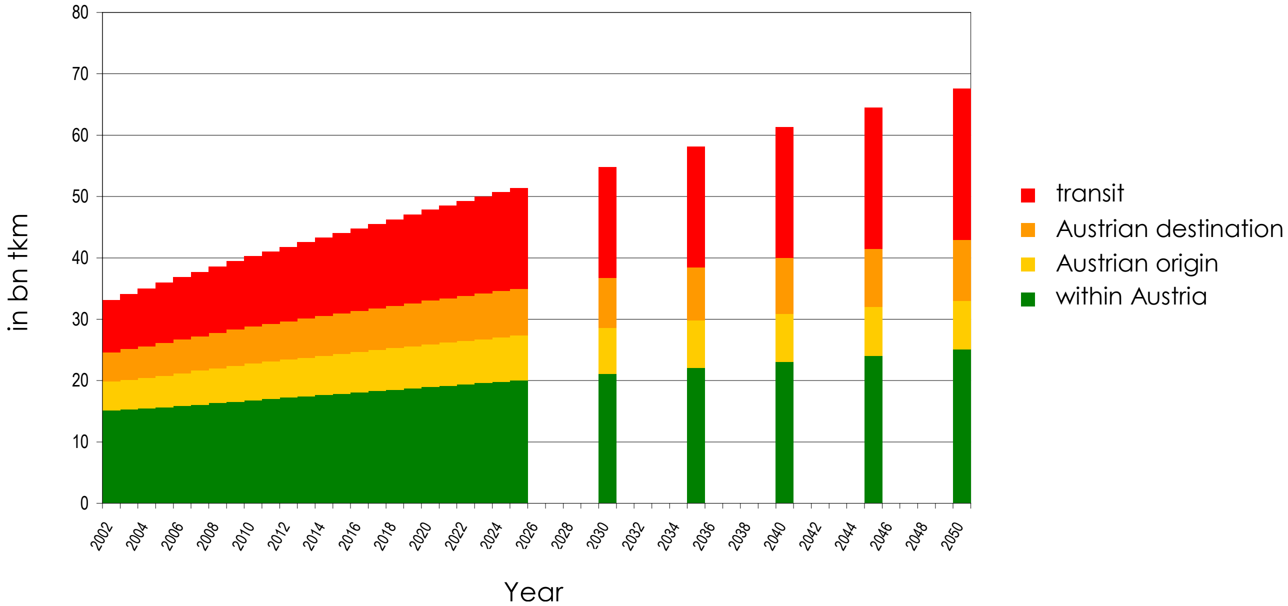
Figure 10.3: Passenger transport development by 2050



Source: Käfer et al. (2008).

For freight transport the performance is expected to increase more significantly – both in road and rail; it is expected to roughly double by 2050 relative to 2008 levels. Road freight transport development is given in Figure 10.3, with transit transport increasing most strongly.

Figure 10.4: Freight road transport Austria by 2050



Source: Käfer et al. (2008).

The decarbonisation of transport – seen from today's perspective – is likely to work along the very same technology wedges as given in chapter 4 for the 2020 time horizon, albeit at a different relative weight.

Technology wedges targeted more directly at the services themselves, such as spatial planning (M-1 – Promotion of an efficient transport saving land use), will gain in importance over time – if the wedge is initiated early enough to enfold its long term impact. Given the achievement of this wedge, the technology wedge public transport (M-2 – Improvement of public transport) and non-motorised transport (M-3 – Extension of non-motorised transport) can serve a broader share of the population, thus enhancing the impact of these two technology wedges in the long term as well – relative to their short term weight.

On the contrary, the large short term success of biofuels (M-7 – Increase of biofuel additions) seems to be limited with respect to substantial further growth, mainly due to competition for land, as we will show below. The technology wedge vehicle efficiency (M-4 – Alternative propulsion technologies) that is a crucial one in quantitative terms already up to 2020, could be exploited further substantially. The technology wedge for freight transport (M-5 – Freight transport) is needed urgently, although it is more difficult to reach a substantial quantitative importance. The lightweight technology wedge (M-6 – Efficiency increase by lightweight construction of vehicles) can substantially be further exploited, but materialises significant energy (and emission) reduction only in combination with M-4 (Alternative propulsion technologies). Technology wedge M-8 (Relocation of fuel consumption) can be assumed to have been fully exploited by 2020 already.

As we will see below in more detail, transport development cannot be analysed in isolation, but a crucial aspect is the way the energy used in transport is produced, in particular what sources electricity is produced from, but also what sources biofuels originate from.

Regarding the share that each of the technology wedges mentioned above could reach by 2050, a recent backcasting study on decarbonising transport (Skinner et al., 2010) concludes that a combination of efficient technologies and biofuels (our wedges M-4, M-6, and M-7) has the highest potential for emission reduction. Their analysis states that these wedges could cause a *decline* in transport GHG emissions by 36% by 2050 relative to 1990 (compared to an *increase* of these emissions by 74% when none of these wedges is exploited). For significant decrease in transport emissions, however – this study outlines a reduction by 89% by 2050 (relative to 1990 transport GHG emissions) – the other wedges need to be exploited as well.

Stated differently, overall the energy efficiency increase of vehicles is estimated to be limited to some 50%, the upper bound to be reached only for some types of vehicles, particularly aircraft and ships (Skinner et al., 2010). Thus, demand side management is needed, such as improved spatial planning to achieve substantial energy and emission reductions.

The question remains, what energy sources will be crucial in order to move towards decarbonisation. Grossmann et al. (2010) compare renewable energy sources and test for the following four criteria: (1) Is the potential of energy supplied by a renewable energy source sufficient to meet at least a considerable proportion of global energy needs? (2) Are necessary materials available or are there intrinsic bottlenecks which can only be overcome with difficulties, if at all? (3) Will the renewable energy technology reach grid parity – and when? (4) Is the required land area sustainably available, and are there significant impacts on water supply or quality? They argue that Photovoltaics (PV) and thus electricity is the most likely candidate to cover future energy demand on a renewable basis. For Austria, for example, they estimate that 2.62% of its land area would be needed to cover total current energy demand by PV only. Comparing electric vehicles (EVs) with the alternative of biofuels, there clearly is a large advantage of PV. For example, in terms of land requirements: "[C]ombustion vehicles driven by biofuel or microalgae would need respectively 300 times (30 times) the area required by EVs driven by PV." (Grossmann et al., 2010: 4852).

Cost equivalence of PV with thermal electricity production (grid-parity) is expected by 2015. Thus, it is rather market penetration of electric vehicles (including to meet particular consumer demands) and the adjustment of infrastructure (provision of recharging infrastructure, infrastructure for renewable electricity supply) that will govern the expansion of e-mobility. Passenger transport can in principle be fully transferred to be fuelled by electricity, both for motorized individual transport and public transport. E-mobility can also contribute to expand the share of modes currently considered non-motorized, such as biking.

Two fractions of transport – to date – remain that cannot easily be fuelled by electricity: air and heavy road freight. For both biofuels seem to be the alternative of choice. For example, Boeing has successfully tested 50% biofuel additions in its airplanes.

Given this remaining biofuel supply for air and heavy duty freight is being covered carbon-neutral (an assumption dependent on wider social developments, such as e.g. the share of meat in food consumption), the GHG emission reduction levels of 80 to 95% relative to 1990 can be achieved in transport by 2050 in Austria.

10.2 Perspectives for 2050 – Buildings

If current structures of energy demand and supply prevail, the future is characterised by an increasing shortage of energy resources and by accelerating climate change. The answer can only be the implementation of sustainable structures of energy supply and use as well as the transformation into a low carbon and low energy society, i.e. focusing on technologies and behavioural changes to reduce energy demand as far as possible to the utmost level. That means decoupling energy supply from CO_2 emissions, increasing energy efficiency and the share of renewable energy sources – by expanding and intensifying the technology wedges for 2020. In the building sector new design and technology concepts have to be implemented which meet the necessary requirements of low energy demand.

The adoption of new technologies will go hand in hand with the implementation of enforced legal standards and codes regarding energy efficiency in the building sector. Energy demand of the new generation of buildings will be nearly zero, as it is also already required by the new European Directive on Energy Performance in Buildings (European Commission, 2010a) and obligatory for all new constructed buildings in Europe after 2020.

Today in Austria Low Energy Standard is mainly applied in the housing sector receiving public funding and the Passive House Standard is already to become state-of-the-art within new construction, and to an increasing extent also becoming more relevant for the renovation of residential buildings. However, there is still a big challenge to implement low-energy and passive house standards in non-residential buildings (mainly service buildings, e.g. offices), which is mainly related to the missing awareness of market actors in this area.

But the future design of buildings is going even further – towards the development and implementation of "zero energy" and "plus energy" buildings.

Zero Energy Buildings do not use fossil fuels and produce all their remaining energy demand (mainly electricity) from renewable energy sources. The shape can be a traditional building, which is in general equipped with energy supplying units such as large solar collectors, photovoltaic systems, building integrated small wind power plants or other combined heat and power systems. By now, there is no exact scientific definition for the zero building standard compared to the existing passive house standard; clear international standards still have to be formulated and translated into national standards and building codes.

Zero energy buildings are based on the following principles: reduce energy demand, use energy gains and avoid installing active heating and cooling systems by implementing proper passive construction measures (e.g. shading to avoid overheating of buildings in summer). Any remaining (very low) demand for heating shall be supplied through low-temperature systems (heat pumps, solar heating & cooling – all in all "flameless" technologies (see also chapter 10.2.2) instead of heating boilers in buildings, except in the case of co-generation systems) or use efficient ventilation and air conditioning systems (HVAC) and highly efficient equipment and lighting.

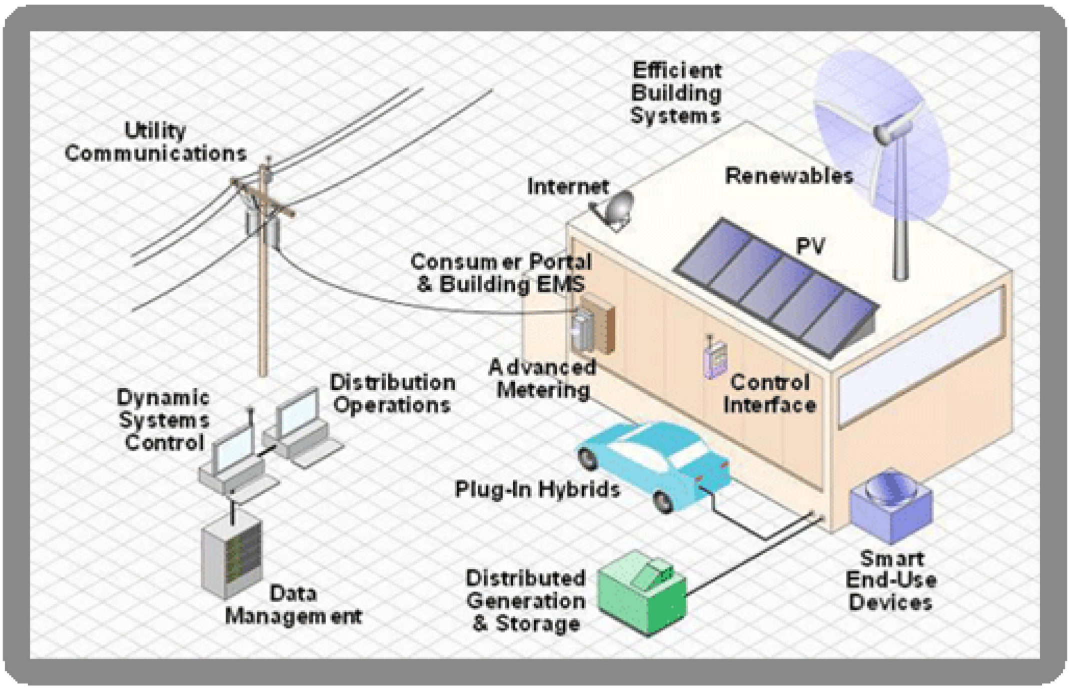
Zero Energy Buildings differ from Zero Net Energy Buildings and Zero Carbon Buildings. Zero Net Energy Buildings are neutral over a year, they deliver as much energy to the supply grids as they use from the grids. Zero Carbon Buildings are carbon neutral or positive and produce enough CO_2 free energy to supply themselves with energy over the year (IEA, 2008).

Plus-Energy Houses comply with the criteria of PHS and are characterised by active power supply and energy-saving equipment used by tenants/owners. The buildings are producing more energy over a year than they require for own consumption. Roof and façades are actively used for e.g. photovoltaic plants. The solar power plant is feeding excess electricity into the local grid, or even charging batteries of electrical vehicles.

Simultaneously these buildings become energy suppliers, e.g. for solar heating and cooling, photovoltaics etc.

The concept of the Plus Energy House is closely connected to the "smart grids" concept that will increasingly play an important role in buildings as well as in cities and in whole regions. Smart grids will enable an efficient integration of decentralised energy supply and storage technologies into existing (local or decentralised) network infrastructure. Smart grids are power supply systems, which support energy and cost efficient operation of the systems through a coordinated management and bidirectional communication between the components of the electricity generation system, supplier, storage and consumer (see Lugmeier, 2009). Figure 10.5 visualises the scheme of a smart grid.

Figure 10.5: Scheme of a Smart Grid



Source: Clean Thinking (2009).

Highest priority in the building sector is to adapt the existing building stock for future requirements. A sustainable development of the building stock will take into consideration environmental, economic and social aspects, i.e. focus on the users (tenants, owners of buildings) and their energy use patterns and training them in "behaving energy efficient".

The implementation and enforcement of a energy-efficient building legislation (amendments to building codes and relevant norms and standards), the continuous quality improvement in the planning and construction sector, including the awareness raising and training measures for planners, architects and construction companies, and awareness measures to influence building users to "behave energy efficient" will be altogether required to realise a significant energy and CO_2 emission reduction in the building sector.

10.2.1 Perspectives for building energy standards by 2050

While nowadays the Low Energy Standard in the renovation sector (specific energy demand of less than 50 kWh/m².a) is implemented by the market, the perspective is that in the nearest future the Passive House Standard (specific energy demand of less than 15 kWh/m².a) will increasingly penetrate the field of thermal refurbishment of existing buildings.

To intensify the implementation of Passive House Standard in the renovation of buildings, continuous technological development of relevant PH components and materials is required, e.g. prefabricated facades and roof systems, which meet highest insulation standards. Prefabricated multifunctional facades, which combine energy supply, thermal and aesthetic qualities will be applicable in the field of renovation. Such multifunctional building elements are: facades systems and roofs, combining the functionality of current standard components, like statics, weather and fire protection with the ability to produce, store, distribute heat. Further examples of building elements are:

Building components, like windows, are able to adapt their transmission on the basis of the intensity of insulation (see BMVIT, 2010a). Roof elements could serve as weather protection and simultaneously meet the insulation requirements, and additionally function as window, solar thermal collector or photovoltaic panel with an energy storage module. Other possibilities could be to integrate heat storage capacities into traditional building components, like ceilings, walls and wall plaster, which will absorb excess heat and release, when required, heat directly into the building. For this, it will be necessary to increase the storage mass through suitable storage materials, like concrete, solid bricks or thick loam rendering, or otherwise by admixing of phase change materials (PCM).

The building of the future will have a multifunctional building envelope where solar thermal and photovoltaic panels are integrated. The development in the field of new buildings will be also directed towards "active solar buildings". Active solar buildings cover the remaining heating (and cooling) demand of 50 to 100% by solar heat (see BMVIT, 2010a).

10.2.2 Perspectives for Heating in 2050

Conventional heating systems will become redundant

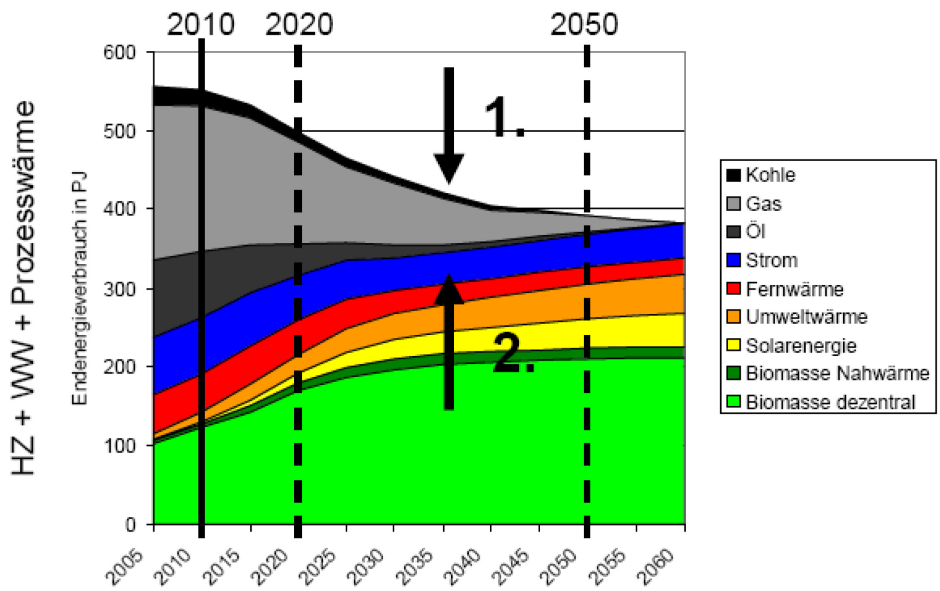
While currently space heating of buildings is based mainly on fossil sources the trend is clearly showing towards renewable energy supply for buildings. Part B, chapter 5 has already shown the perspectives for residential buildings as well as the expected changes for heat supply of buildings by 2020. The fossil sources oil and gas will decline by 2020 (oil from 29% to estimated 20%, gas from 20% to estimated 15%, compared to 2008), the renewable sources will increase from 33% (2008) to estimated 44% in 2020. This trend continues in the future so that it will be possible that fossil sources will be close to zero up to 2050. The future will be characterised, as mentioned above, by a substantial reduction of the heating demand in buildings, caused by their thermal optimisation. A reduction of energy demand for heating and hot water of about 45 – 55% by 2050 is forecasted by Biermayr and Müller (2010). In order to meet the remaining (low) heating demand innovative heating systems based on renewable sources will be used. The big challenge for developing a sustainable heat supply sector will be the shift away from combustion technologies to "flame-less" technologies (low temperature systems). These include especially highly efficient low temperature systems based on solar energy, heat pump systems (and other systems based on geothermal sources, such as deep drillings) and the use of biomass (solid, liquid, gas) in small cogeneration units (these require however a furnace or boiler), to be used individually and in combinations. Innovative technologies will be used, like cogeneration, gasification, or use of (industrial) waste heat (provided e.g. through district heating systems). In the case of further installation and extension of district heating systems, especially the reduced demand of buildings for heat has to be kept in mind.

The unavailability of sufficient heat densities will partly result in inefficient systems and thus render extensions barely economically attractive. Exceptions are district heating systems in larger cities (e.g. Vienna) where waste heat is used to a large extent.

Strong efforts have also to be undertaken to optimise the performance of heating systems, especially in the field of combined systems, such as biomass boilers in combination with solar heating and hot water, hybrid systems – solar heat combined with heat pumps (see Part B, chapter 5.1.4 solar heat in 2050), further the involvement of solar heat into micro-, local and district heat systems. The hydraulic integration of solar heat into the grid (flow supply or return lifting, centrally or decentralised supply) and especially the hydraulic integration of large collector arrays (faulty wiring strategies, stagnation performance) as well as further problems have to be solved (see BMVIT, 2010a).

Figure 10.6 shows the assumed trend of the fuel mix up to 2050 and raises the question of the feasibility of 100% renewable heat (see Biermayr et al., 2009).

Figure 10.6: Scenarios for a 100% renewable heating sector



Source: Biermayr et al. (2009).

Increasing the penetration of solar thermal heating in 2050

The future use of solar heat is characterised by a broad range of applications and the ambitious objective not to generate any CO_2 emissions from the production of heat and hot water. Hence, great efforts in all fields (from research to industry and commerce and to users) will be necessary to upgrade the solar heat for all suitable uses. Such progressive applications could be "Active Solar Buildings" which cover their heat demand at 100% by solar heat, in the fields of building renovation systems of active solar renovation need to be developed, which cover the remaining heating and cooling demand at a minimum of 50% (see chapter 10.2.1 and BMVIT, 2010a).

As mentioned in Part B, chapter 5 a wide range of improvements are therefore necessary: storages with high energy density, new materials of collectors and components are to be developed, the use of hybrid systems using solar heat and heat pumps, where higher solar gains are obtainable and improved seasonal performance factors to be achieved. Also the integration of solar heating into district heating systems based on biomass etc. has to be considered. Furthermore, the structure of the building envelope is to be changed, building components are to be developed, which are combined with solar functions or heat storage and thin but high efficient insulation material (see also chapter 10.2.1).

The main technology developments are specified in the following paragraphs (see BMVIT, 2010a):

New collectors

The focus will be on full plastic collectors, that means substitution of the current tube fin absorber (metal) by the new large area absorber, which basically requires a changed design of the glazed flat plate collectors and on the improvement of the efficiency of the collectors. In the nearest future the focus will be on novel collectors in composite design for the application in small solar plants with successive optimisation of the materials and substitution of peripheral components, like collector tub in order to increase the function integration and reduce the number of components in the collectors. Collectors in fully plastic design will be especially applicable in large scale solar plants.

New materials

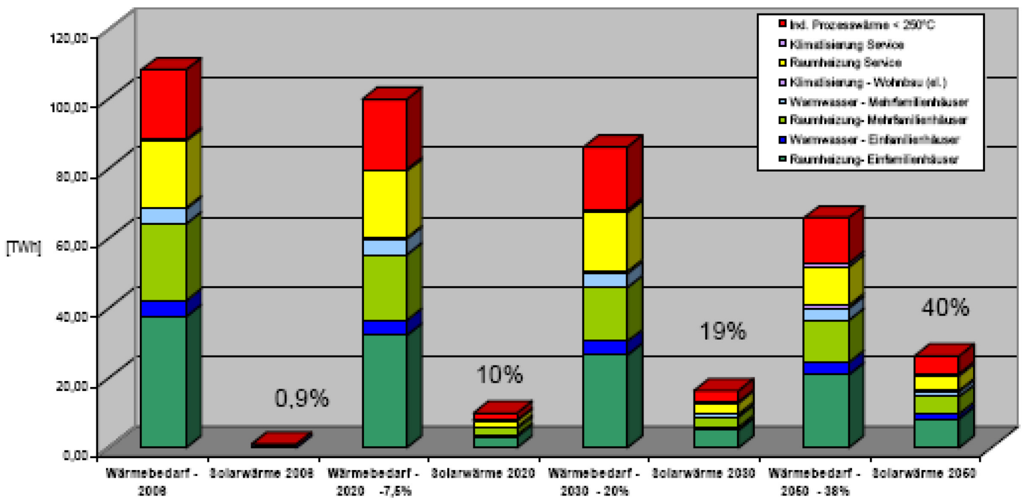
The main focus will be on the development of novel plastic-compounds, which have technical, economical and ecological gains compared with the currently used materials. Changes of the characteristic profiles of the material, which permit an optimised design of the collectors (e.g. thermotrop materials for the protection against overheating) and materials, which contribute to an increase of the collector and system efficiency (e.g. selective absorber coating) are therefore necessary. During the adaption of the compounds the cooperation between partners following the value added path of polymer materials, like primary producer, compounder and fabricator is of essential importance.

Thermal storage

With regard to storage technology especially the development and the application of new materials are an important topic. Storage media, like phase-changing-materials (PCM, thermo-chemical reaction partners), have to be significantly improved with respect to energy density in the complete system during the next years in order to achieve higher power density compared to water storages. Beside the development of new materials with substantially improved characteristics compared to currently used silica gel, zeolite, paraffin especially the optimised system integration as well as the reduction of the production costs play an important role. Furthermore a large potential exists not only in the diminution of the storage volume of latent-heat storages, but especially in the integration in differing modes in the building or in the technical equipment. The new generation of storages has to be compact, cost effective, safe, clean and easy to handle

The short and long-term potential of solar heat in Austria up to 2050 with respect to efficiency effects in the building and industry sector is demonstrated in Figure 10.7. Here, the contribution of solar heat to the low temperature heating and cooling demand for industrial process heat (< 250°C), for the service sector and the residential sector is illustrated. Based on a 7.5% reduction of energy demand in the building sector through renovation up to 2020 and a 10% coverage of the then reduced demand by solar heating systems in 2020, the long term contribution of solar heating in 2050 may be around 40% of the heating demand (in 2050). Therefore an installed capacity of 46 GW_{th} (equivalent to 8 m² installed collector area per inhabitant) would be necessary (see BMVIT, 2010a).

Figure 10.7: Short and long-term potential of solar heat in Austria



Source: BMVIT (2010a).

10.2.3 Perspectives for solar electricity production in 2050

Impressive progress in PV technology has been made over the past decades. This is evident by the price reduction (roughly a factor of 5 over the past 20 years), by the efficiency increase of commercial and laboratory technologies (typically by 50% over the same period), by a broad technology portfolio and finally by a strongly improved system reliability and yield.

The period until 2050 will show further maturing of commercial technologies, leading to flat plate module efficiencies in the range of 10-25% (35% for concentrators) and a significant decrease of electricity production costs from PV (as low as range of 0.05-0.12 €/kWh[60]). All kinds of PV technologies, such as crystalline silicon, thin film and other new concepts may be

[60] See European Commission (2005).

significantly present on the market. PV system elements will develop into versatile building components (facades, roofs, glazing), which will facilitate a standardised and specific use on a large scale. The perspective is that almost all new buildings will be fitted with PV arrays, and many will become net producers of electricity.

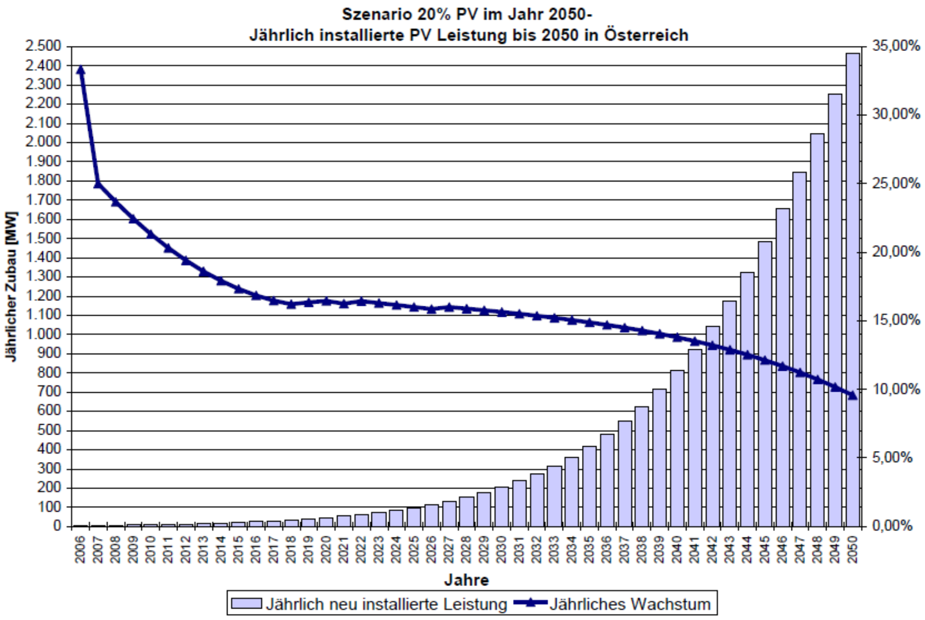
In 2005, the Photovoltaic Technology Research Advisory Council (PV-TRAC) initiated by the European Commission has argued that by 2030 with ambitious, but realistic, growth figures the installed capacity may increase to around 200 GW (200 TWh) in the EU, and 1,000 GW (1,000 TWh) worldwide in 2030, representing 4% of world electricity production. The forecast for PV development in Austria is even more optimistic, according to the PV Roadmap for Austria (Fechner, 2007): a target of 20% of the domestic consumption has been formulated for the year 2050. The 20% target would mean an installed capacity of approx. 22,500 MW_p. Necessary growth rates to achieve this target are given in Fechner (2007).

Table 10.2: Average annual growth rate of installed PV capacities in Austria

2006-2010	25%
2011-2020	18%
2021-2030	16%
2031-2040	15%
2041-2050	12%

Source: Fechner (2007).

Figure 10.8: Scenario for installed PV capacity in Austria until 2050



Source: Fechner (2007).

10.2.4 Perspectives for efficient household appliances and electric equipment in 2050

The spectrum of appliances, lighting and electric devices used in households is very wide, and so is the range of energy consumption of products offered. It is expected that the use of electric appliances will significantly increase within the next years, so the future challenge will be to increase the penetration rate and use of energy optimised appliances through all product ranges available.

Widespread use of electronic household and office equipment leads to a significant overall electricity consumption related to standby. For the year 2005 the European Commission estimated that approximately 4 billion installed products in the EU feature standby mode, leading to an electricity consumption of close to 50 TWh, corresponding to 20 million t CO_2 emissions (European Commission, 2008c). Typically, on a household level about 10% of the electricity demand is lost through stand-by use (DENA, 2010).

Technological improvements will need to put a focus on reducing and eliminating stand-by consumption throughout all product ranges.

Awareness raising campaigns aimed at increasing demand for products with no or low standby mode, and educating users to switch or plug off equipment when it is not used, have and continue to be the most important measures, to some extent leading to better "switch off habits" and influencing purchasing decisions regarding equipment with low electricity consumption in standby and off mode.

However, if applied appropriately, standby functionalities can help save electricity because they provide a convenient way to switch equipment into a condition with reduced power consumption compared to the "active" condition that provides the main function, which typically uses much more power. In order to optimise the combined active/standby/off electricity consumption of a certain product, consumption in standby/off mode must be minimised, while ensuring that standby functionalities are not lost for the product.

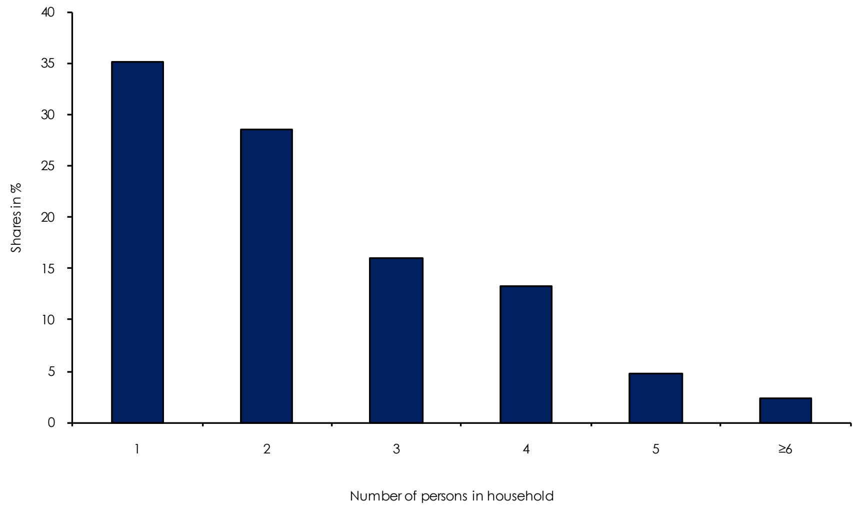
The way forward in the area of household appliances and electric equipment is definitely the sole use of low energy equipment. As mentioned, many manufacturers already offer a set of products in the efficient spectrum even at comparable prices, however such products have not become the standard so far. The reasons are mainly unawareness of buyers/consumers and very often still higher prices. Many household appliances already have the EU label, which informs the customer about the appliance's energy consumption according to efficiency classes A to G. Information and continuous awareness raising for private and institutional buyers (e.g. through greening public procurement) is necessary to make the right buying decisions in favour of efficient products, and on the other hand the efficient use of equipment is another important aspect to realise a significant saving potential.

The estimation is that a minimum of 30% could be saved by eliminating standby consumption, and another minimum of 20% by replacing equipment with low energy products and efficient user behaviour, in total at least 50% of the household electricity demand could be saved (see EcoTopTen, DENA 2010).

Awareness raising and information is e.g. supported by "klima:aktiv", the Austrian Climate Protection Initiative of the Ministry of Environment. The information platform www.topprodukte.at is a platform displaying the most efficient appliances of a kind of product, and furthermore b2b.topprodukte.at provides information for institutional buyers how to procure equipment taking into consideration energy efficiency criteria.

The continuously increasing electricity demand of households of about 1.2% per year (see also Part B, chapter 5) is the result of a rising number of electric appliances. Changes in life style, like an increase of single households, the use of dwellings as "home office" and other developments, such as the increased use of mobile systems (internet, social networks, etc.), have created and will in the future create increased demand for appliances, mobile communication and ICT applications demanding electricity. Furthermore new forms of living will emerge, e.g. community and more generation dwellings due to the decrease of the birth rate and increased life expectancy. Figure 10.9 shows the current household size in Austria. While the number of households is growing, the size of households decreases.

Figure 10.9: Number of persons per household



Source: Statistics Austria.

In addition to Figure 10.9 Table 10.3 illustrates the average electricity demand of different household sizes. Single households (SH) may have a different user behaviour than multi-person households (MPH), however there is a degression of electricity demand in larger households, but also an average 40% energy saving potential between low and high electricity demand. Empirical studies of the Energy Agency Nordrhein-Westfalen, Germany, showed that e.g. the average electricity demand in single households is ca. 2,000 kWh/a and person, in 6 person households ca. 960 kWh/a and person.

Table 10.3: Average household electricity demand

in kWh/a	low	middle	high
1 Pers HH	under 1,250	from 1,250 to 2,330	above 2,330
2 Pers HH	under 2,120	from 2,120 to 3,940	above 3,940
3 Pers HH	under 2,720	from 2,720 to 5,040	above 5,040
4 Pers HH	under 3,100	from 3,100 to 5,760	above 5,760

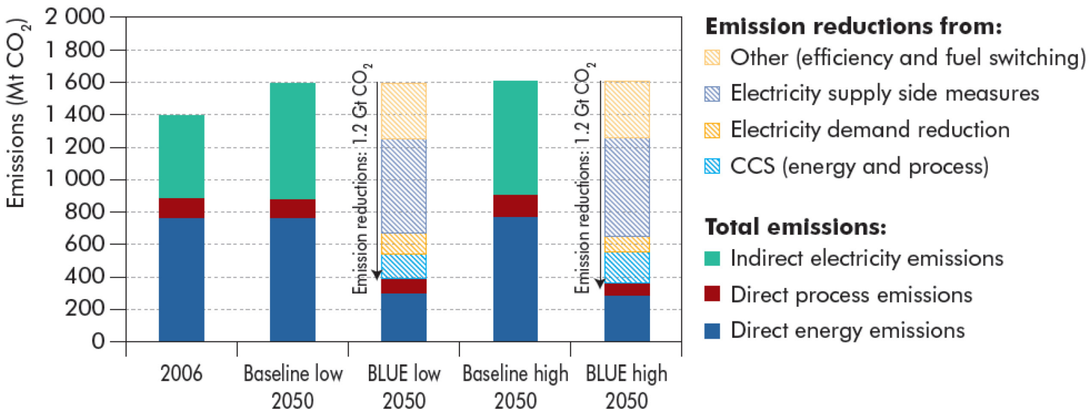
Source: Statistics Austria, ESV, own calculations.

Considering the continuation of the demographic and life style trends the only way to steadily reduce electricity demand of households is an increase of energy efficiency of household appliances by the replacement of inefficient obsolete appliances as well as changes in user behaviour (see also Part B, chapter 5). Therefore substantial awareness raising regarding energy saving has to be enforced and supported by appropriate incentives, so that by 2050 the low level of electricity demand per household (see Table 10.3) can be achieved. The rapid implementation of minimum standards of consumption of household appliances is also required as one result of comprehensive analyses of energy savings also in the household sector (see Energieinstitut Linz, 2010).

10.3 Perspectives for 2050 – Industry

Undoubtedly the industry sector will have to contribute to the (vague) goals of Europe towards a low carbon society. Instead of an expected increase from 1,400 million t CO_2 in 2006 (sum of direct electricity emissions, direct process emissions and indirect electricity emissions) to 1,600 million t in 2050 (baseline scenario of (OECD/IEA, 2009), a reduction of 400 million t/a needs to be aimed at.

Figure 10.10: Total industrial CO_2 emissions in OECD Europe in the baseline and BLUE[61] scenarios, 2006 and 2050



Source: OECD/IEA (2009).

The perspectives with respect to energy demand and emission of GHGs from industry in Austria in 2050 will largely depend on the following developments:

- economic development (GDP growth)
- industry structure (globalisation)
- development in other sectors (passive houses instead of conventional houses, lightweight cars instead of SUVs, more electronics in all products, new communication technologies, etc.)
- specific energy input (improvements in energy efficiency)
- change in the mix of energy sources (driven by prices, regulations, availability, technological progress, etc.)

In Austria industry accounted for nearly 28.6% of total energy demand in 2008. The sector was responsible for about 35% of the CO_2 emissions according to the energy demand of which the largest shares originate from the iron and steel industry, paper, pulp and print, non-metallic minerals, and from petrochemicals.

It is expected that the energy mix in industry will change considerably until 2050 with the use of coal and oil declining, while the shares of natural gas and biomass will increase. However,

[61] The ETP 2010 Baseline scenario follows the reference scenario to 2030 outlined in the World Energy Outlook 2009, and then extends it to 2050. It assumes governments introduce no new energy and climate policies. In contrast, the BLUE Map scenario (with several variants) is target-oriented: It sets the goal of halving global energy-related CO_2 emissions by 2050 (compared to 2005 levels) and examines the least-cost means of achieving that goal through the deployment of existing and new low-carbon technologies (Figure ES.1). The BLUE scenarios also enhance energy security (e.g. by reducing dependence on fossil fuels) and bring other benefits that contribute to economic development (e.g. improved health due to lower air pollution).

without ambitious efforts to reduce energy demand, industrial energy use in 2050 is still at least 19.7% higher in 2050 than in 2008 (OECD/IEA, 2009).

Final energy consumption in the production sector can be analysed using a systems approach. In general, the life cycle of a product covers at least five steps:

1. Primary production of materials (mining, harvesting, …)
2. Basic material production (iron from ore, plastic pellets from crude oil, cement, bricks, etc.)
3. Final material production (steel sheets, plastic parts, concrete parts, tubes, wires, etc.)
4. Final products (computers, houses, cars, bread, beer, etc.)
5. Recycling, reuse and deposit.

Moreover, there is also the use-phase of the products with its associated demand for energy and other resources and materials like water, lubrication oils, pressurized air, and the corresponding emissions. Since the listed production steps are all in series, their efficiency gains can be multiplied. In order to achieve a reduction of 80% over the 40 years from now (2010) to 2050, a production chain of 5 steps at a given and constant output, each step has to improve by 27.5% on average.

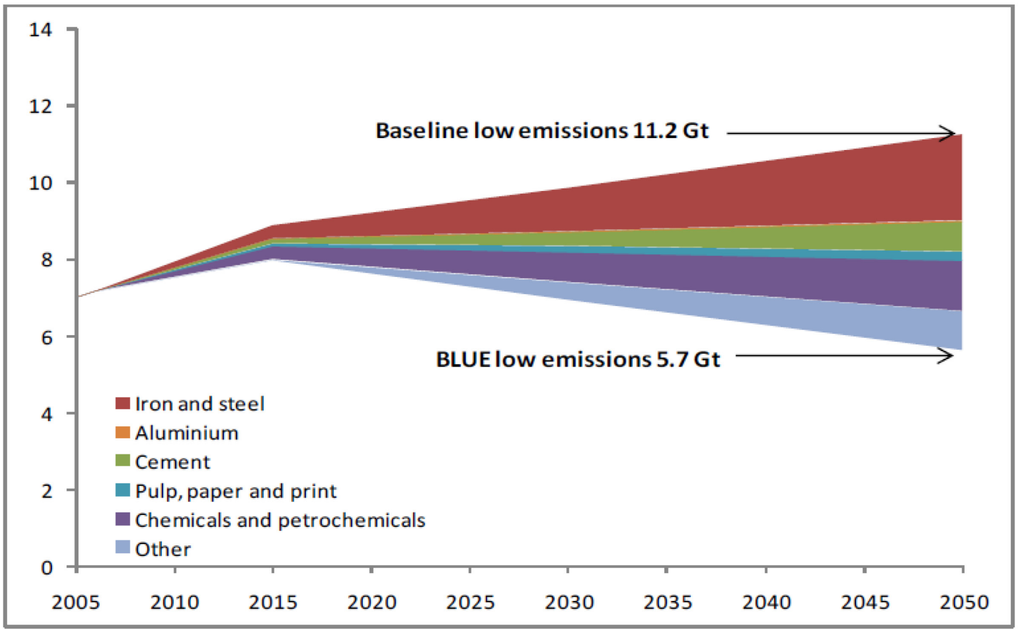
$$(1-0{,}275)^5 = (1-0{,}8)$$

Taking into account a time period of 40 years, the annual gain in efficiency per step in the life cycle has to be 3%.

It can be assumed that the technology wedges defined for the period until 2020 will be valid until 2050. Radical changes are not ruled out, but unpredictable.

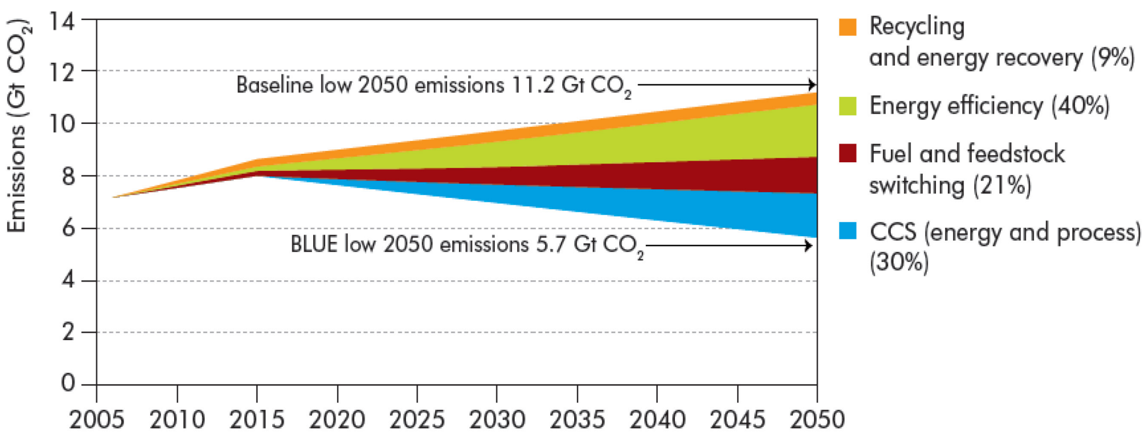
There are several studies for sector specific technology developments. Some of the key findings for the relevant sectors are discussed in the publication of the International Energy Agency "Energy Technology Transitions for Industry: Strategies for the next industrial revolution" (OECD/IEA, 2009). According to these analyses global emissions from industry could be reduced by halve compared to the baseline 2005.

Figure 10.11: Contributions of the main industrial sectors to a reduction of GHG emissions



Source: OECD/IEA (2009).

Figure 10.12: Technologies for reducing direct CO_2 emissions from industry, 2006 to 2050



Source: OECD/IEA (2009).

CO_2 emissions reductions will be needed from all industry sectors. But action is particularly crucial in the five most energy-intensive sectors: iron and steel, cement, chemicals and petrochemicals, pulp and paper. Together, these sectors currently account for 64% of total direct CO_2 emissions from industry, with the following relative shares: iron and steel 19%, pulp and paper 12%, chemicals and petrochemicals 12%in Austria.

The main findings from a global perspective discussed in the following are from the IEA-study "Energy Technology Transitions for Industry: Strategies for the next industrial revolution" (OECD/IEA, 2009). The relative value will be different for Austria, with more weight to the "Iron and Steel" and the "Pulp and Paper" sectors.

Iron and steel

The global deployment of current best available technologies (BAT) could deliver energy savings of about 20% of today's consumption. The reductions will be generated through new technologies such as smelt reduction but also through fuel switching (coke to gas-based direct reduced iron. Biomass (charcoal), plastic waste and CO_2-free electricity also offer interesting opportunities. CCS is an option that would allow the sector to achieve deep reductions in emissions in the future.

Cement

Reducing CO_2 emissions in the cement sector is very challenging owing to high process emissions related to the production of clinker, the main component in cement. Improving energy efficiency at existing plants, investing in BAT for new plants, and increasing the use of alternative fuels and clinker substitutes will not be enough to achieve net emissions reductions in the future (OECD/IEA, 2009).

Chemicals and petrochemicals

The full application of best practice technologies (BPT) in chemical processes could achieve energy savings 15% (OECD/IEA, 2009). Additional measures such as process intensification and process integration, the greater use of combined heat and power (CHP), the utilisation of recycled materials and recovered energy will reduce emissions additionally. However, there are important barriers which constrain the exploitation of this theoretical potential. To achieve future CO_2 emissions reductions in the sector, a range of new technologies must be developed and successfully applied. These include novel olefin production processes such as the wider use of catalysis, membranes and other new separation processes, process intensification, and the development of bio-based chemicals and plastics.

Pulp and paper

A transition to current BAT could save up to 25% of energy used today. Reducing emissions in the sector will require additional improvements in efficiency, fuel switching to biomass, and the increased use of CHP. Promising new technologies such as black liquor gasification, lignin removal, biomass gasification and CCS will also be needed to achieve significant emissions reductions.

Cross-cutting options

There are important cross-cutting technologies and options for reducing CO_2 emissions from a range of sectors, of which increased energy efficiency, BAT for new installations and fuel switching to biomass are the most significant and thus deserve particular attention for technology development. Other options include efficient motor and steam systems, CHP, and increased use of recycled materials.

In the following some subject areas are addressed that will play a crucial role to achieve emission reductions in industry in Austria until 2050. They continue the development already assumed and described in the storylines and technology wedges for industry until 2020, but assume acceleration in diffusion and implementation. With respect to the type of measures, their relative contribution stays constant over the whole period until 2050.

10.3.1 Passive house technologies for production halls and offices

It can be assumed that all newly built production halls and offices will comply with passive house or plus-energy building standards from 2020 on. Production halls and office buildings will thus be characterised by better insulation, solar (air) heating systems and the use of waste heat from processes and/or cogeneration.

For the existing building stock we expect a fast replacement and improvement in terms of energy demand for heating and cooling. Production lines have a rather short useful life so the chance to modify the whole site with a corresponding effect on energy efficiency exists, if economic or legal incentives are in place. The energy demand for heating and cooling buildings in the production sector can be down to 10% by 2050 compared to current energy demand.

10.3.2 Cogeneration

The amount of low temperature heat in production processes will increase in the wake of the development of new technologies, a shift towards biotechnology and a change in materials from metals to polymers. Assuming a rise in electricity prices, the competitiveness of cogeneration units will improve. From a current perspective, the potential for the use of cogeneration units could decrease if there is a significant shift towards biomass as the main fuel, as cogeneration is more expensive compared to gas turbines and diesel motors, on the one hand. On the other hand this relationship could change if one takes changes in relative energy prices into consideration. Waste heat from cogeneration will almost exclusively replace low temperature heat and will therefore be applied in the food sector, metal treatment and textiles.

10.3.3 Process intensification and integration

Process intensification and heat integration in production processes will remain the most profitable activity to reduce emissions for the industry. These approaches usually pay off in a few years and will increasingly be integrated into the design of production units and processes. Since no process technology will stay unchanged over the next 30 years, it will be essential to concentrate on the energy efficiency of new designed production lines and not only on the improvement of existing ones.

Heat integration is important for existing production lines, since it can be added without substantial changes. The European roadmap for process intensification (Senter Novem, 2007) estimates the potential for emissions reduction depending on the industrial sector between 20 and 50%.

10.3.4 Efficiency of technologies using electricity

It is very likely that the demand for electricity will continue to increase in the next decades as it did in the past. This is due to a shift towards electricity in process heating, additional electricity demand as a consequence of measures to reduce the consumption of water and thermal energy (more filters, membrane units, heat exchangers, control devices, etc.). This makes the effective/efficient use of electricity even more important than today. The spectrum of electricity consuming technologies is wide and so are the technological potentials for energy saving.

We can expect a development push in the efficiency of electric motors. As all existing drives will be replaced in the next decades, it is extremely important that only efficient units are installed since the technological choice determines electricity demand over the service life of the newly installed drives. The expected continuous progress in the development of drives will very likely be incremental without any new break-through technology that would achieve reductions of e.g. factor10 or more. The expected increased demand for communication technologies indicates that this is also an area where new more energy efficient approaches are needed.

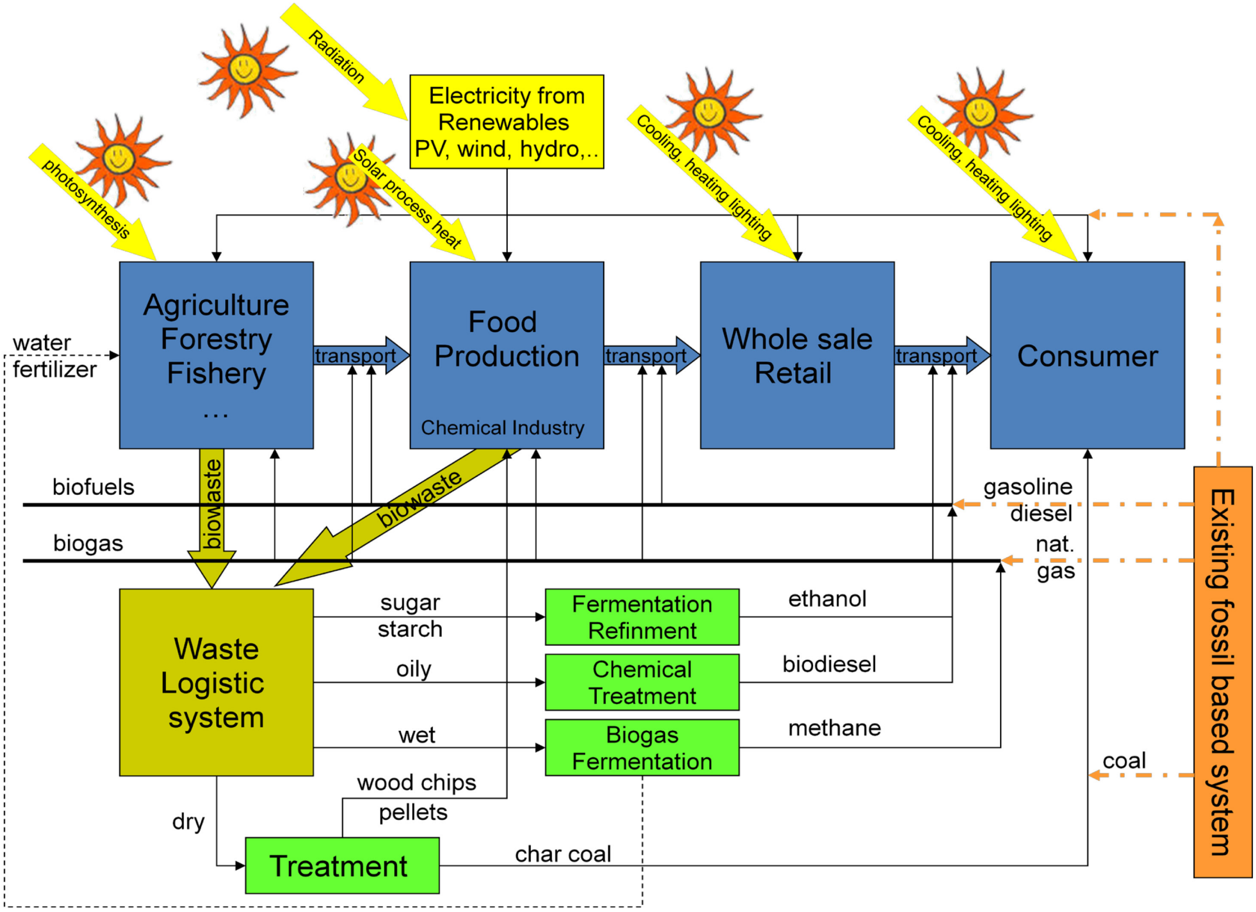
A changed mix in materials used will affect the electricity demand as well. This regards the production of the materials (less steel = more polymers) but also the fabrication processes (from welding to gluing).

10.3.5 Switch within fossil fuels and increased use of biomass and solar energy

Biomass will gain in importance not only as an energy source, but also as the basis for chemicals (plant-based chemistry). The whole use of plant material in biomass refineries (replacing partially petrochemical refineries) is an important tessera in the mosaic of a low carbon economy. Thermal solar energy will be integrated into the production processes and heating systems at low temperatures. They will always need integration into a classical energy supply system and/or need high storage capacities. Biogas from organic waste will be a standard technology in sectors where organic waste is available. The goal for 2050 is the complete avoidance of fuels for any application with temperatures below 100°C. These energy services can be covered by solar heat and waste heat from processes and cogeneration.

Figure 10.13 shows the food chain based on the utilisation of the whole plant and solar energy. Industries based on renewable resources from agriculture and forestry can (easily) reach a Zero-Carbon state in 2050.

Figure 10.13: Low carbon production chain in the food industry



Source: Own illustration.

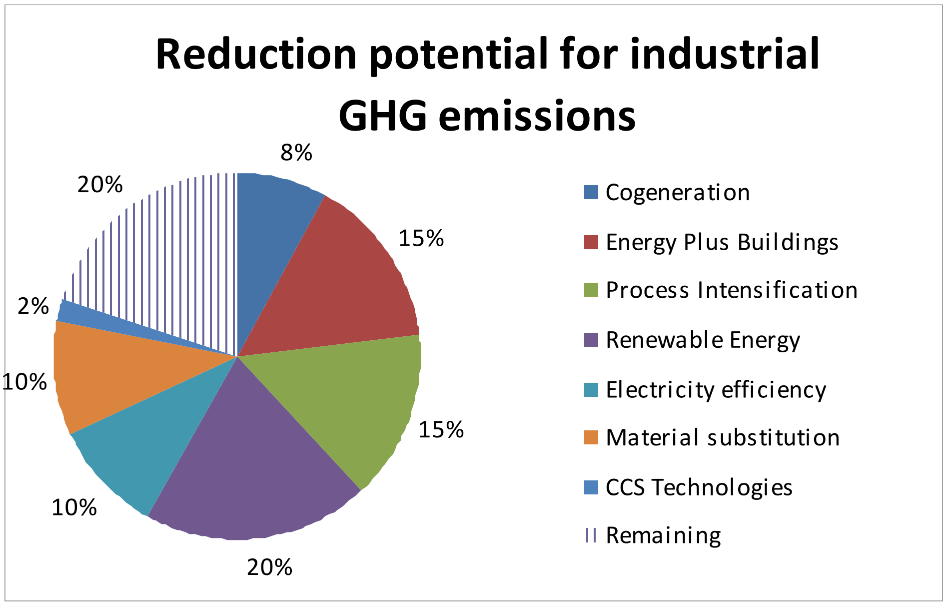
10.3.6 Further possible developments

CCS technologies (carbon capturing and storage) are not expected to play an important role within the industrial sectors, except at very large installations at steel plants, cement kilns or large chemical complexes. Recycling of materials will influence the energy need as well. Higher recycling rates and the use of secondary materials are an important strategy.

10.3.7 Conclusions

Industry, as an important user of energy, will have to contribute to a further reduction in the emission of GHGs. Since in the next decades practically all production lines will be replaced by new ones, it is extremely important to integrate new technologies already in the design processes. A change in building and mobility infrastructure and products will require new production units and opens a window for more efficient processes from the first step in the design process.

Figure 10.14: Potential contribution of industry to a reduction of Austrian GHG until 2050 by 80%, shares based on industrial structure in 2005



Source: Own calculations.

The relative potential to contribute to emission reductions stems from various technical options as illustrated in Figure 10.14 (based on present energy consumption structures):

- Cogeneration of low-temperature heat and power in medium sized units: -8% fossil fuels (reduced energy demand mainly in the energy supply sector).
- Passive houses and energy-plus buildings for office buildings, production halls and storages resulting in an almost complete avoidance of room heating: -5%.
- Process intensification through new technologies, heat integration and process optimization for production processes in any sector: -15%.
- Shift to renewable energy (solar process heat, biomass heating systems, biogas from waste, PV,…) mainly for low temperature processes, in selected cases with cogeneration; biomass refinery concepts for the utilization of the whole plant in the food chain: -20%.
- Improved efficiency in electrical applications (drives, cooling,…): -10%.
- Material substitution including a shift from steel to polymeric materials, concrete to wooden structures and more light materials in general: -10%.
- CCS technologies will still play a minor role in industries: -2%.

In order to achieve the goal envisaged several measures have to work together:

- Policy framework: adequate incentives for GHG-reduction through economic and legal changes. Energy should become part of operating permits for new technologies; an option could be globally tradable emission reductions; infrastructure for gas and electricity should aim at increasing the share of renewables.

- Technologies: More energy efficient technologies and technologies based on renewable resources have benefits besides a reduction in emissions as they e.g. reduce the dependency on imports of fossil energy.
- Goods and services: design guidelines for a longer lifetime and an easier reparability of goods; more services sold than products, more service intensive products
- Infrastructure: an increase in the recycling rates of materials is necessary.
- RD&D: Continuation and enforcement on research to zero-emissions technologies; improved conversion of renewables to services, logistics and biomass refinery concepts. Sector specific break-through technologies.

10.4 Perspectives for 2050 – Energy supply

It is never too early to develop perspectives about the long-run perspectives of energy supply since energy systems are heavily dependent on structures decided upon in the past decades. This is the reason insights about the potential and desirable supply structures in the next decades are needed for shaping the next investment decisions early on.

There are basically two fundamentally different approaches for developing perspectives about energy supply: the supply focused approach and the demand focused approach. Only an integrated approach that takes into account the interrelation between supply and demand is, however, capable of providing constructive insights into the potential futures of our energy systems.

10.4.1 The limits of the conventional approach: Extrapolating current supply structures

Most conventional analyses, above all many of the International Energy Agency (IEA), are based on extrapolating current supply structures. The limits of this approach are obvious if we look at some key components of energy supply.

If people living in China and India would use the same amount of crude oil per capita as people living in Europe, world production of crude oil would need to double. There is simply no evidence that this can be done in view of the ongoing peak-oil discussion. Similar arguments limit a multiple expansion of natural gas supply from current volumes, not only because of limited reserves but also because of the more difficult distribution logistics required either via pipelines or via an energy-intensive liquidification process and transport by tankers.

The major energy consumers as China and the United States are heavily dependent on coal in particular for electricity generation. Since coal compared to other fossils is still available in abundance, major efforts are made to improve coal-based transformation processes by more efficient combustion technologies, by adding an additional conversion process via synthetic fuels, and by limiting greenhouse gas emissions from coal by developing carbon capture and storage (CCS) technologies. The common characteristic of all these technology options for coal is a considerable increase of generation costs. The currently estimated costs for CCS start beyond 70€ /t CO_2. For reducing global GHG despite these technologies the use of coal, however, has to be limited.

440 nuclear power plants currently contribute less than 6% to global primary energy demand (IAEA, 2006, IEA, 2010). Doubling their number and continuing past trends would only cover the additional energy requirements of two years. In addition, construction times of more than ten years for new nuclear installations suggest no perspective for a significant contribution of nuclear energy to global energy supply if past trends – i.e. rising energy demand – continue.

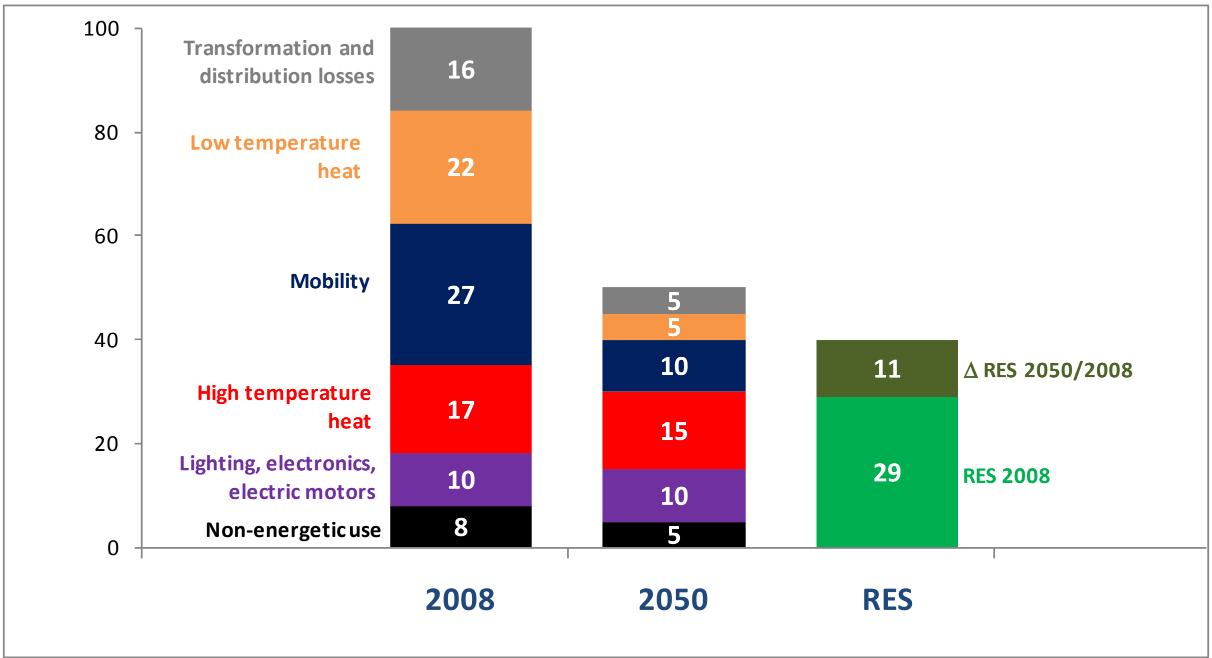
With these obvious limits for fossil and nuclear energy attention turns to renewables. A first look, however, reveals also limits for most renewable energy sources. Biomass faces the competition for land with food and fibres and is very land-intensive compared to other renewables. Biofuels are characterised by low efficiency rates in mobile combustion engines. There are limits to hydro installations because of negative environmental impacts. Also wind turbines are confronted with these allegations. Thermal solar is available on various scales and is very cost-efficient in small scales in order to supply heating and cooling for buildings. Although the direct conversion from sunlight to electricity via photovoltaics is currently the most expensive renewable energy source major technological breakthroughs are expected both by improving the current technologies and by switching to technologies based on abundantly available organic substances.

Extrapolating the current energy supply structures of energy on a global scale thus do not offer a perspective for 2050.

10.4.2 A radical innovative approach: Matching the energy demand of a high-efficiency energy system by an adequate supply structure

Forecasting energy supply by looking into the future via the rear view mirror of past trends is not viable. Instead of the future based on past developments a methodology of a backcasting from potential viable futures to the present should be applied. We demonstrate this for the Austrian energy system.

Figure 10.15: Final energy demand in Austria by use category and share of renewable energy, 2008 and 2050



Source: Statistics Austria (2009b); own calculation.

Starting point is the current demand for energy split up into various categories of use. Figure 10.15 normalises current energy flows to 100 in 2008 thus providing the percentage shares of categories for this year. Figure 10.15 shows that about 15% of potentially available final energy is lost in transformation and distribution processes. Although this is a relatively low share compared to many other industrialised countries there is still a substantial potential for switching to highly efficient renewables or to co- and polygeneration technologies and lowering distribution losses through more decentralised structures and improved spatial planning. By 2050 losses could be reduced by a factor of three.

22% of energy is currently needed for low-temperature heating. There is a high potential for improving the thermal structure of the building stock and for switching to passive-house and even plus-energy standards in new buildings. Thus even substantially higher levels of energy services, i.e. a much larger volume of buildings for housing and production, could be maintained by a forth of the current flows of energy for low temperature heat in 2050.[62]

27% of the current energy flows are used for mobility, almost exclusively in combustion engines technologies. Given the high potential to reduce redundant energy services by improved spatial planning and changes in time use and life styles as well as by a substitution

[62] Energy is, however, not the only limiting factor for an increasing stock of buildings. Other aspects such as land consumption have to be taken into account.

of conventional cars by fully electrically powered cars in light-weight designs based on polymers energy flows for mobility could be reduced by a factor of three by 2050.

In almost all industrialised countries as in Austria losses, low temperature heat and mobility account for about two thirds of energy consumption. Using existing and currently emerging technologies the energy volumes for these three energy categories could be cut by factors ranging between three and four by 2050.

But even the remaining energy use categories have a potential for increasing energy productivity. Outstanding are the prospects for switching to light emitting diodes (LED) for lighting which provide the same energy service with less than 5% of the energy needed for an incandescent lamp.

By 2050 countries like Austria could hence meet all desired energy services by at most half of the current energy flows. These radical improvements in energy efficiency open surprising new perspectives for the role of renewables in energy supply. If we follow suggestions discussed within the European Union that Europe should aim for a share of renewables of 90% by 2050, For Austria this would mean an increase of the current volume of renewables by about 50%, that is an expansion from about 30 units in 2008 to 45 units in 2050 (see Figure 10.15). Given the potential and the expected dynamics of costs and technologies this a very reasonable perspective.

10.4.3 Some guidelines for restructuring the current energy systems from the perspective of 2050

The challenge in the project EnergyTransition lies in the proposition of concrete technological changes for the Austrian energy system until 2020 for the areas mentioned above along with alternative supply structures of energy that do not contradict a more long term perspective of the overall energy system in 2050.

For energy supply this means to think of changes in infrastructure and fuel shifts in electricity and heat generation until 2020 that will not result in undesired technological lock-ins or prove as sunk costs. Thus a guiding principle for the proposed technological changes in energy supply up to 2020 was to have the longer 2050 perspective in mind.

The expected structures of the energy system in about four decades determine the next steps to put the current energy system on a viable transformation path. The following guidelines for policymakers, companies and consumers can be derived:

(1) Viable energy systems will require a multiplication of current energy productivities

In mobility, buildings and manufacturing sufficient technologies are either already available or visible for providing the currently required energy services with one forth or even less of energy flows.

(2) Higher energy productivity is coupled with higher energy quality

If we measure the quality of energy by exergy, that is the ability of a certain type of energy to provide work, the transformation processes are characterised by lower energy volumes but with higher exergy. This means, for example, there will be a lower demand for low temperature heat but a higher demand for electric appliances, electronics and motors.

(3) The energy supply mix needs to adjust to these shifts in demand

The expected demand shifts in the quality of energy need to be reflected by a matching supply mix with a higher share of high exergy energy such as electricity and a lower share of low exergy energy as low temperature heat.

(3) The energy supply structure will become more decentralised

This is caused both by the inherent decentralised availability of renewables as thermal and electrical solar, wind, hydro and biomass and the need to locate generation closer to the applications in order to reduce distribution and transformation losses. In addition all thermal transformations should be done as close as possible to the locations where heat is needed.

(4) Primary energy is to be used and reused in a cascadic structure

Some feed stocks as crude oil but also biomass can be transformed both into materials (e.g. for producing polymers and other structures) and energy (e.g. heat and electricity). These feed stocks need to be used in the full cascade of their potential use, i.e. priority is given to the use as materials which should be recycled and only afterwards used as input for the energy system.

10.4.4 Key energy supply technologies expected to emerge by 2050

These are some key technologies for redesigning the supply structures.

(1) Thermal transformation technologies for heat and electricity

According to the guidelines developed above the scale and location for technologies that supply heat and electricity should match demand, i.e. they should be as close as possible to the demand for heating and cooling. The adequate transformation technology will be a co- or poly-generation unit based either on a combustion engine or a (micro) gas turbine using initially natural gas but switching to gas from biogenic waste. Thermal stand-alone technologies either for heat and electricity thus should be phased out.

(2) Energy from buildings

Buildings may play a substantial role not as energy consumers but as suppliers of energy. Thermal and electric solar technologies integrated into roofs and facades could provide surplus energy to the grids for heat and electricity. Additional components in the energy system of a building will be heat pumps and – in a reverse cycle – cooling units. Micro wind turbines for buildings could also generate electricity.

In a transition phase service buildings as hospitals, hotels with swimming pools and office buildings with poly-generation facilities could be developed as focal points for the distributed generation technologies for heat and electricity to come.

(3) Smart grids for heat and electricity

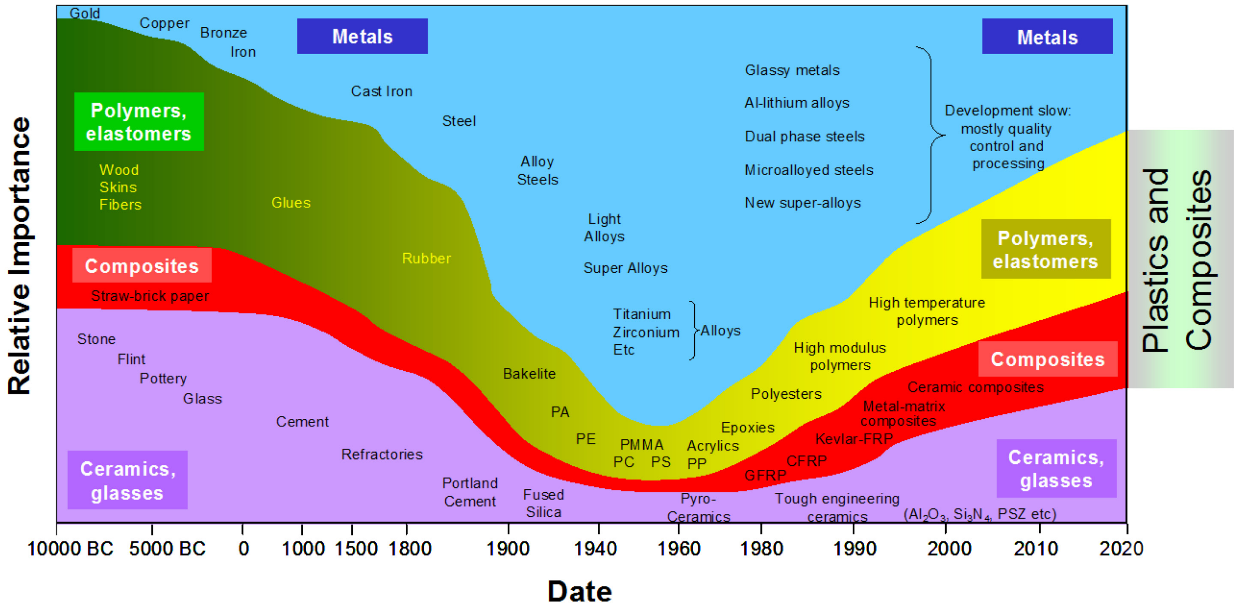
Shifting thermal transformation to the location of demand for heat reduces the distance for heat transport. Together with the sharp decline in demand for heat in buildings because of their improved thermal efficiency this questions any major investments in grids for heat with a big central transformation unit.

Even more pronounced is this shift to decentralised structures for electricity because of the inherently decentralised availability of renewable energy and the perspectives of electric cars whose batteries serve as a storage device for the electricity grid.

10.5 Perspectives for 2050 – Materials

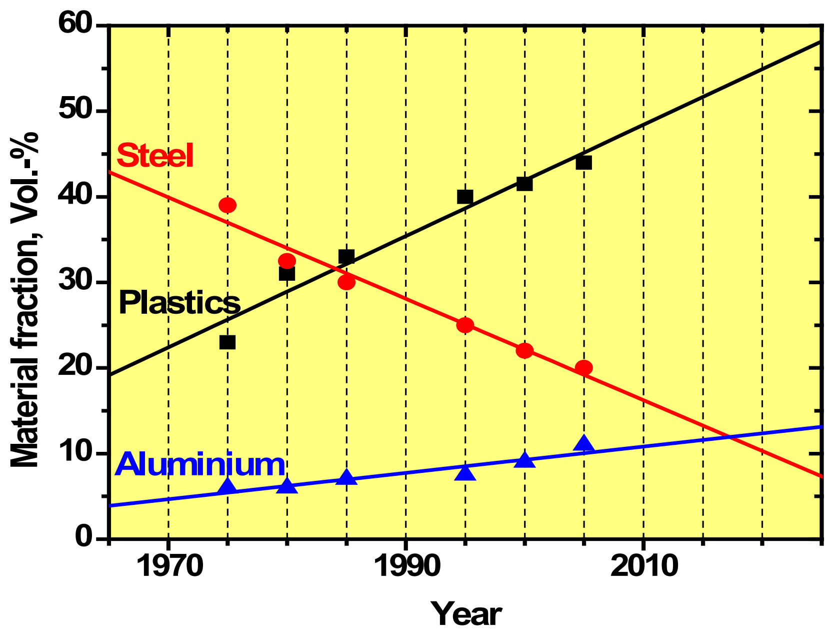
While the key role of materials in the development of the human society and civilization in general is well recognized, it is difficult to make detailed predictions on the development for the next decades. Nevertheless, the overall trends and perspectives are rather obvious as depicted in Figure 10.16 taken from the Material Selection Handbook by Prof. Ashby of the University of Cambridge. According to this figure, the relative importance of materials over the past 50 years has started to undergo a significant transformation, with metals being the dominant engineering material class around 1960. Meanwhile plastics and composites and to a certain degree novel glasses and ceramics have become increasingly important, a tendency which is expected to continue in the foreseeable future. In fact, the prediction in Figure 10.16 for 2020 is based on an analysis of material applications in the automotive industry, which was then generalized in its tendency to engineering material applications as a whole. Specific data in support of the depicted development in Figure 10.16, in particular the increasing utilization of polymeric materials, are provided for the example of material applications in automotive vehicles in Figure 10.17.

Figure 10.16: Relative importance of material use



Source: Ashby (1999).

Figure 10.17: Material fractions in automotive vehicles since 1970



Source: Schlarb (2005).

As pointed out in Part A, chapter 4, materials and material technologies will of course also play an increasingly important role in the energy system, both in terms of significantly enhanced energy efficiency for specific energy services but also in terms of energy supply related to renewable energy technologies including the entire energy transformation chain. Several aspects related to the potential of alternative and novel material solutions towards improved energy efficiency and renewable energy supply technologies are also addressed in Part A, chapter 4, making reference to specific examples in the sectors buildings and living, and vehicles and mobility.

In terms of the longer-term perspective an important shift is envisaged in the role of materials in technology systems from simply being structural or functional materials for specific parts and components to a significantly stronger service oriented role, which aims at the enhancement of systems efficiency, effectiveness and functionality, providing higher quality services. In other words, next generation materials will be developed and adapted to specific needs and functionalities with a much stronger focus on the optimisation of the systems functionality and performance. Among all material classes, polymeric materials, composites and hybrid materials offer the largest potential for tailoring novel materials towards specific multi-functional property and performance profiles.

As to material performance improvements, it becomes increasingly apparent, that they play an important role in the overall energy efficiency improvements in existing technologies and applications. Of course, they also represent the key parameter in novel technologies. While all material classes (metals, polymers and ceramics) have been and will continue to be improved further in terms of properties and performance, the most significant improvements in the future are again expected in the field of polymeric materials and advanced composites and hybrid materials. There are several key fields of energy technology functions in which materials play a major role in terms of improved energy efficiency and a higher quality of energy services. These include:

- In the field of enhanced energy efficiency:
    - Materials for thermal functions such as required in heating and cooling of buildings and the living environment.
    - Materials for structural and primarily mechanical functions in buildings and vehicles aiming at light-weight and ultra-light-weight constructions and designs, which is of prime importance particularly in the entire mobility sector.
- In the field of energy generation (i.e., harvesting of renewable energies) and energy transformation and transportation:
    - Materials for direct solar technologies (solar-thermal and solar-electrical),
    - Materials for indirect solar technologies (e.g., wind energy harvesting with wind mills of various designs and size scales from micro-scale to large-scale; high voltage DC cables for efficient electric energy transportation),

    - Materials for hydropower and wave-power energy generation, particularly also of small size scales (small and micro-turbines).
- In the field of energy storage:
    - Materials for batteries and capacitors of various size scales (e.g., large capacity light-weight batteries of high energy density for vehicles),
    - Materials for solar-chemical conversion technologies (e.g., conversion of atmospheric CO_2 into hydrocarbons or alcohols; electrolysis of water to produce hydrogen)
    - Thermal storage materials with significantly enhanced energy density compared to current water based sensible heat stores.

For energy efficient buildings, material and component technologies for building construction elements and building infrastructure (thermal insulation, windows, fresh air supply and air exchange, etc.) have reached a rather high standard, so that future activities will be driven by cost reduction measures in the production and conversion technologies and by larger production volume benefits (i.e., economies of scale). While the importance of the current material classes (ceramics, glasses, metals, wood, polymers) will remain, perhaps with a certain shift in the material mix (e.g., enhanced utilization of wood based materials), future development efforts essentially will be directed towards further improvements and optimization of current technologies in terms of functionality, architectural building aesthetics, ease of construction and installation and last-but-not-least costs. In general, the tendency for industrial pre-manufacturing of building structures and components initiated in the past decade by the enhanced requirements and quality standards for building components meeting “passive house standards” will continue, thus leading to improved service and lifetime performance while simultaneously being more cost effective.

On the other hand, in terms of renewable energy technologies, there is a huge potential for material-driven innovations in the field of solar thermal technologies (novel solar thermal collectors and collector systems with enhanced plastics use up to plug-and-function all-polymeric solutions), solar electrical technologies (thin film photovoltaic modules of enhanced efficiency based on industrial processing technologies; wind turbines of different power categories, especially also small and ultra-small wind power generators in composite and hybrid material design), and energy storage technologies (e.g., novel lithium-polymer batteries, novel hybrid material based capacitors and super-capacitors).

In the field of mobility and vehicles, energy efficiency is primarily related to the total vehicle mass, to aspects of aerodynamics and outer shell vehicle design, to the rolling resistance of the tires and to the type and choice of the engine. Here too, materials and material technologies play a crucial role, if not the key role, in all of these fields. As to the total vehicle mass, the aerodynamics and the rolling resistance, advanced light weight materials and structures based on composites and hybrid materials as well as the increasing use of high performance plastics and elastomers (e.g., for tires) are the main drivers of innovation. While polymeric materials already offer a wide variety and a multitude of advantages in terms of efficient and low-cost conversion technologies, for advanced composites and hybrid materials such conversion technologies are currently the focus of scientific and industrial development worldwide. Their successful implementation represents the prime prerequisite for ultra-lightweight vehicles based on a further significantly enhanced fraction of polymeric materials and on the application of novel composite and hybrid materials and structures.

A final aspect of future material technologies and their impact on the energy system is related to raw material availability and the material process chain (i.e., material production and conversion technologies). For example current estimates of the static reserve of raw materials availability based on 1998 economic conditions are 30 years for copper, which is a major material in solar-thermal collector systems. Moreover, for Ga, Nd, In, Ge, Sc and Pt demand linked to new technologies is expected to exceed current world production by factors of 1.6 to 6 by 2030 (Angerer et al., 2009).

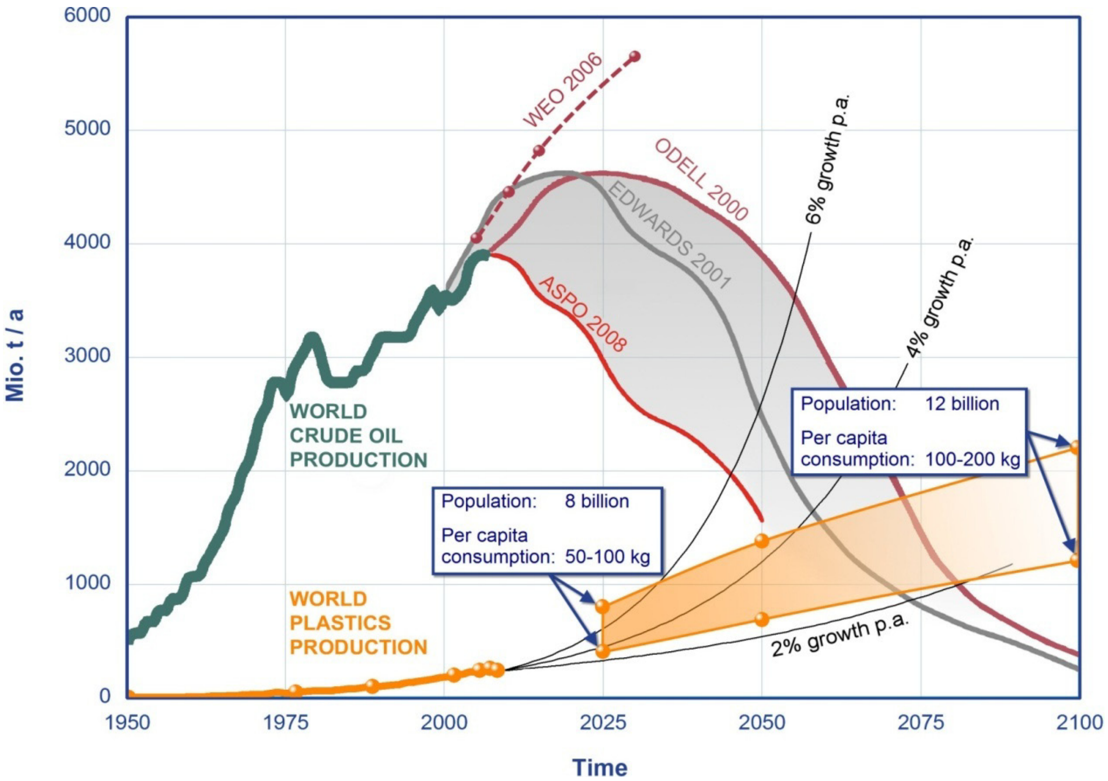
Considering the rising importance of polymers, the aspect of sufficient raw material availability for the next decades has been addressed most recently by Lang and Kicker (2010). Currently polymeric materials and plastics are produced predominantly from crude oil, consuming about 5% of the total crude oil production annually. Based on various plastics growth scenarios and on various peak-oil scenarios, the authors pointed out that the fraction of overall crude oil needed for plastics will significantly increase in the next decades (Figure 10.18).

Figure 10.18 combines various lower and upper bound scenarios in terms of future oil production and future plastics growth in a single chart. The oil production scenarios include those of Odell (2000), Edwards (2001) and ASPO (2008) all of which reach to 2050 and beyond, respectively. For comparison also included is the World Energy Outlook 2006 scenario (IEA 2007), which, however, contains a forecast to 2030 only. As "official" plastics growth scenarios up to 2050 by industry associations and alike are difficult to obtain, two approaches where followed in Figure 10.18. One approach is based on the crude oil need for current production volumes which were assumed to grow by rates in the range from 2 to 6 % p.a. (black solid lines in the illustration). The other is based on assumptions for population growth (8 billion in 2025, 12 billion in 2100), superimposed with lower/upper bound assumptions for the annual average per capita plastics consumption (50 and 100 kg per capita and year in 2025; 100 and 200 kg per capita and year in 2100).

The superimposed illustration in Figure 10.18 offers several remarkable insights. As to the crude oil production scenarios, for 2050 the numbers vary substantially from about 1,500 to 4,000 million t/a. Nevertheless, taking for example a plausible lower bound range for plastics production in 2050 of 800 to 1,000 million t/a, this would imply that, depending on the oil production scenario, 20 to 50 % of the crude oil production would be needed for the production of plastics. This numbers are by a factor of 4 to 10 higher than the current 5% of crude oil use for plastics production. One can easily imagine, that any such a scenario will have significant consequences to both, the future of fossil fuel based energy supply and the future development of the entire plastics industry.

Based on such scenarios as illustrated in Figure 10.18 combined with considerations of technology and innovation opportunities for the fossil fuel and the plastics industry, in Lang (2006, 2010) it is concluded that the interests of the oil and gas industry and the solar industry will converge. Among other reasons, this will be the case also in order to secure a sufficient raw material supply for higher value-added products such as polymeric materials. After all, many oil/gas production companies are also directly or indirectly involved in the production of plastics. In addition, alternative raw material resources for the production of renewable resource based polymers either in terms of biomass or by proper conversion technologies utilizing atmospheric CO_2 to produce hydrocarbons (e.g., methane) or alcohols (e.g., methanol) and alike will become increasingly important by 2050.

Figure 10.18: Comparison of plastics growth and peak-oil scenarios



Source: Lang – Kicker (2010).

11 Summary and Conclusions

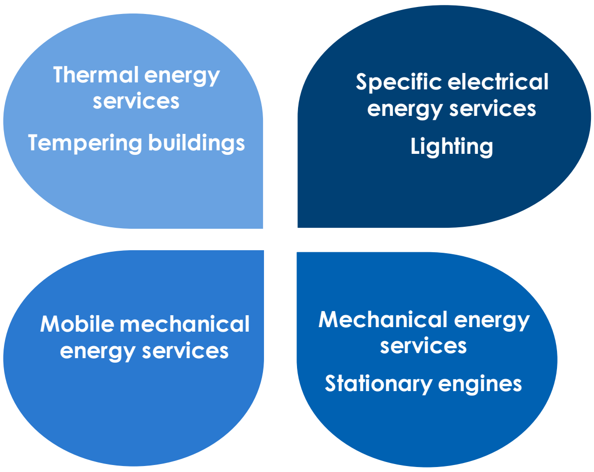
11.1 Introduction

The analysis of energy systems usually focuses on energy flows from primary energy sources to final energy demand by households and companies. It is, however, not the quantity of energy consumed by households and companies that is relevant for welfare but the energy services delivered. Hence, new concepts for the energy system are required that shift the focus from energy flows to energy services. The research project EnergyTransition[63] aims at expanding the analysis of energy flows through a closer look at energy service demand and technological options for application and transformation technologies.

The following energy services are distinguished for the analysis:

- Thermal energy services on different temperature levels that comprise low temperature applications in buildings (heating, hot water) and high temperature applications in industrial processes (e.g. industrial furnaces, kilns, etc.).
- Mechanical energy services to satisfy mobility needs on the one hand and for stationary engines in households and companies on the other hand.
- Specific electric energy services for lighting, electronics and other appliances.

Figure 19: Energy services



Source: Own illustration.

Energy flows and thus the energy demand of households and companies depend on the application technologies used to provide the energy services. In buildings e.g. the energy

[63] The project EnergyTransition was funded by the Austrian 'Klima und Energiefonds' and was carried out within the research programme 'Energie der Zukunft'. The research programme 'Energie der Zukunft' was the result of a strategy process 'Energie 2050' of the Austrian Federal Ministry for Transport, Innovation and Technology. EnergyTransition as an interdisciplinary basic research project touches several thematic areas of the programme but has a focus on the area foresight studies.

required to deliver the energy service "well tempered living space" depends on the thermal quality of the building (thermal transmittance of walls, windows, roof etc.) and the heating system. With respect to mobility services the design of vehicles (e.g. lightweight construction using polymers) and the choice of the propulsion system (combustion or electric engine) are of relevance. Furthermore, a strong interrelation between energy services and selected material technologies for application technologies exists.

The application of (innovative) technologies and the respective investment decisions by firms or households depend on the one hand on prices for energy and for the technologies and on the other hand on institutional factors. Regulations (e.g. building codes, emission standards) or soft measures (e.g. mobility management) influence technological as well as societal or institutional innovations and technology choices. The amount of energy services consumed and the application technologies used in turn affect the requirements for primary energy supply and transformation processes for the generation of electricity and heat. Both, the transformation process and the distribution of energy entail losses. Thus, at this level decisions about transformation technologies, the primary energy sources used and the structure of the distribution network affect the efficiency of the energy system. Improvements and emission reductions can for instance be achieved by substituting stand-alone generation of heat or electricity by co-generation technologies or the increased use of renewable energy sources.

Regarding the restructuring of energy systems in order to be compatible with climate policy objectives three basic principles should be considered:

- *Low energy* needs to be dealt with as first priority in a restructuring process. It addresses any activities that aim at providing energy services with less energy flows. This includes the elimination of redundant energy services (e.g. in terms of person kilometres but not the access to goods and persons) just as well as innovations that improve the efficiency of transformation and application technologies.
- *Low carbon* aims at a controlled phase-out of fossil energy sources and serves climate policy objectives as well as energy supply security considerations. This, however, can only be achieved in combination with significant energy efficiency improvements. A complete substitution of fossil energy by renewables without reduction in demand is not feasible in the medium term.
- *Low distance,* finally, is related to the local/regional availability of renewable energy sources and distributed generation. This also requires new network and distribution structures for electricity and heat. Another relevant aspect in this context is the organisation of everyday life and avoiding redundant transport e.g. by improved spatial planning, tele-commuting etc.

EnergyTransition sets out a methodological frame for restructuring the energy system and integrates the idea of technology wedges by Pacala and Socolow (2004). It then applies the developed methodology – with a focus on energy services – to different areas in the Austrian energy system. The empirical application for the Austrian energy system implements the concept of technology wedges for the areas mobility, buildings, manufacturing and electricity and heat supply. For these areas storylines for each technology wedge describe the evolvement of energy services, energy flows, CO_2-emissions and technologies with a horizon until 2020. This is extended by technology specific investment and operating costs. Whereas the time span until 2020 comprises concrete calculations of energy and emission changes as well as investment and operating costs a qualitative outlook until 2050 is presented.

11.2 The extended technology wedges approach for Austria

Pacala and Socolow (2004), Socolow et al. (2004) show that a stabilisation of global greenhouse gas emissions[64] using existing technologies is possible in the next 50 years and that a broad diffusion of innovative technologies is required afterwards to reach the concentration goals. Each of the technology categories that are available in the short term can according to Pacala and Socolow (2004) make a significant contribution to the mitigation of emissions on a global level. A broad spectrum of options is considered that comprises energy efficiency improvements in buildings, transport and energy generation, a reduction of the emission intensity of energy generation (natural gas instead of coal, ...), carbon capture and storage as well as reforestation measures.

According to Pacala and Socolow (2004), the challenge is the broad application and a large scale up of the available technologies on the one hand, and in the initiation of climate-relevant research and development (R&D) on the other hand.

Pacala and Socolow (2004) offer a highly operational approach for analysing induced technological change. Concerned with technologies of the energy sector that have an impact on CO_2 emissions, they propose a restructuring of the global energy sector based on currently known and available technologies that would stabilise the level of carbon at seven billion tons of carbon per year (GtC/year) for the next five decades. Today we agree that a stabilisation in the next 50 years is not sufficient and new technologies have to be introduced immediately for further reductions of the emissions.

In the study EnergyTransition the concept of technology wedges by Pacala and Socolow is taken as a starting point and extended with respect to technology options for Austria.

One of the extensions of the concept of technology wedges concerns the focus on energy services discussed above. Three main areas are identified for the analysis:

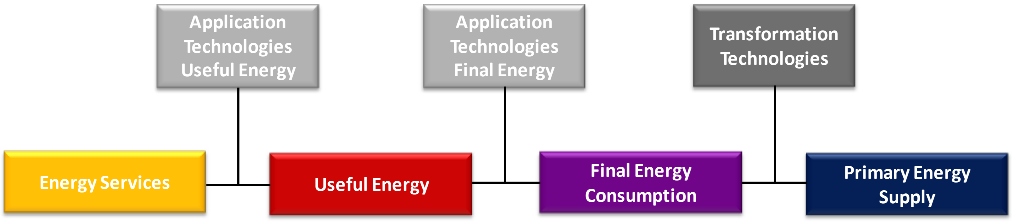
- buildings,
- mobility, and
- manufacturing.

For these sectors desired energy services are defined (e.g. comfortable room temperature, person or ton kilometres). The analysis of the energy system contrary to common approaches

[64] This corresponds to global emissions of about 42 Gt CO_2e. Business as usual forecasts assume a doubling of this value until the middle of the 21st century (Nakicenovic, 2005, Stern, 2006).

thus starts at the "end" of the system: the welfare generating energy services. From there the whole energy cascade is traced back to final energy demand and primary energy supply. Application and transformation technologies used to generate energy services determine final energy consumption and primary supply (see Figure 2).

Figure 20: Structure of the energy cascade



Source: Own illustration.

Technology wedges are then defined for the energy services required and underpinned with a detailed storyline. The focus on energy services extends the notion of technological options as used in the original technology wedges concept: Behavioural changes as for example fewer kilometres driven due to altered preferences or changes in spatial planning are also explicitly considered as an option for reducing energy demand and GHG emissions just as e.g. electric vehicles. Thus, the technology portfolio deviates from the definition of technology in a narrow sense.

In the approach presented in EnergyTransition the concept of technology wedges is specifically applied to the Austrian energy system. Each technology wedge represents an option to reduce CO_2 emissions by a certain amount until 2020. The basic concept of technology wedges is extended in three ways:

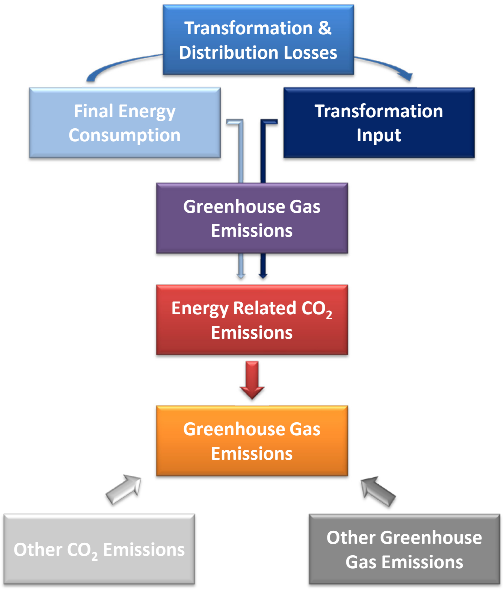
- The technologies are embedded into an integrated structural model of the Austrian energy system that starts from energy services and ends with primary energy flows. The quantity of energy flows depends on the application and transformation technologies implemented.
- The characteristics of all technologies are described in storylines in a uniform framework. The description includes economic parameters such as investment and maintenance costs and energy relevant parameters both in the investment and in the operating phase.
- Economic impacts from the implementation of different technologies are analysed for the investment and for the operating phase.

11.3 The reduction triangle for Austria

Technology wedges focus on emission reduction potentials of different technologies. Modelling of technology wedges therefore requires a reference scenario for the development of emissions. This scenario represents the upper boundary of the reduction triangle from which changes in emissions related to different portfolios of technology wedges are subtracted.

The starting point for the reference scenario is a projection of energy flows which reflects an extrapolation of historical trends based on forecasts of economic development[65]. The scenario consists of two components (see Figure 3). The first component (demand component) extrapolates final energy demand differentiating between economic sectors as well as between energy sources and energy use categories. The second component (supply component) builds on final energy demand and extrapolates transformation input in energy generation plants by energy source. Based on projected energy flows CO_2 emissions are calculated. In addition, non-energy related CO_2 emissions and other greenhouse gas emissions are projected for the emissions reference scenario based on historical trends.

Figure 21: The modelling approach for the reference scenario



Source: Köppl et al. (2009).

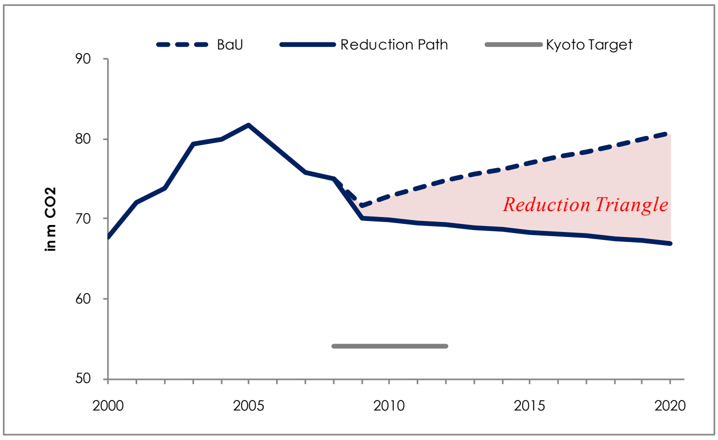
Figure 4 presents the reference path for Austrian CO_2 emissions as well as the reduction path according to the EU Energy and Climate Package (European Commission, 2008a, 2008b). CO_2 emissions are estimated to rise from 87 million t CO_2 in 2008 to 93 million t CO_2 in 2020 in the reference scenario.

According to the approach by Pacala and Socolow (2004) a reduction triangle for Austrian GHG emissions is defined in line with the EU Energy and Climate Package. The reference

[65] The reference scenario represents a possible path for energy demand and emissions along past developments. It does not explicitly depict energy services as analysed in detail in the technology options for the areas buildings, mobility and industry.

scenario and the reduction path - which is derived from the 2020 targets of the EU Energy and Climate Package – define the emission reduction requirement until 2020, the so called "reduction triangle". The methodology for developing the reference scenario as well as assessing the development of final energy demand, electricity and heat generation and GHG emissions until 2020 is described in detail in the full report of the project EnergyTransition. The reduction requirements until 2020 compared to 2005 GHG emissions and the reference path yield the reduction triangle as illustrated in Figure 4. The reduction requirement to comply with the EU targets is 8 million t[66] CO_2 compared to 2008. As we can observe a reduction of CO_2 emissions between 2005 and 2008 the reduction requirement with respect to the base year 2005 of the EU Energy and Climate Package is 15 million t CO_2. The difference in CO_2 emissions between the reference scenario and the emission target in 2020 is estimated to amount to 14 million t CO_2.

Figure 22: Reduction triangle for Austria (in million tons CO_2)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations. – The Kyoto target in this graph represents only the reduction requirements for CO_2 based on the assumption that the Austrian Kyoto target is equally distributed over all categories of greenhouse gases.

11.3.1 Methodological approach for implementing technology wedges

Technological and behavioural options to reduce final energy demand and associated emissions in the areas buildings, mobility and manufacturing constitute different potentials and follow specific storylines. In order to illustrate the cascade of the energy system a common methodological approach for modelling the technology wedges for final energy demand is therefore needed.

[66] According to the calculation of CO_2 emissions in the EnergyTransition project. Deviations from official emission data are quantified and described in the final report of the project. The reduction requirement for CO_2 with respect to the base year 2005 in the EU Energy and Climate Package amounts to 15 million t CO_2. The significant difference in the reduction requirements with respect to 2005 and 2008 is the result of an overall decrease of CO_2 emissions of 6.7 million t between the two years.

The method developed in the project EnergyTransition uses five central variables for describing changes in final energy demand and in emissions for each technology wedge:

- *S* for energy service,
- U for *effective useful energy*,
- *u* for useful energy intensity (amount of effective useful energy[67] U per service unit S, *u*=*U*/*S*),
- *F* for final energy demand, and
- *f* for final energy intensity (amount of final energy F per useful energy, *f*=*F*/*U*).

The development of these central variables until 2020 is expressed in indices (2008 = 100). The reductions in final energy demand and emissions depend on the development of energy services as well as on changes in useful energy intensity and final energy intensity which depict technological and behavioural changes. The effects on emissions are caused by changes in the amount of final energy demand on the one hand and the structure of energy demand by energy source on the other hand (see below).

The central equation for the development of final energy demand over time t is:

$$(1) \qquad F_{w,t} = \frac{S_{w,t} * u_{w,t} * f_{w,t}}{10{,}000}$$

Final energy demand for a specific activity (*w*) in one year thus results from the amount of energy service demanded (*S*, e.g. living space, person kilometres) multiplied by useful energy intensity (*u*) and final energy intensity (*f*). In the storyline the shape of the diffusion path of technologies or behaviour changes is explicitly described.

Given a certain path for the demand for energy services (determined e.g. by behavioural changes) changes in useful energy intensity and final energy intensity determine energy demand. Variations in useful energy intensity occur through technological changes like an improvement in the building stock. Changes in final energy intensity result from improvements in transformation technologies such as engines or heating systems. These technological aspects are based on the storylines developed for various activities using a bottom up approach.

Based on equation (1) technology wedges for final energy demand can be expressed using the following variables:

- $\Delta a_{w,t}$ for changes in useful energy intensity and energy services, and
- $\Delta f_{w,t}$ for additional changes in final energy intensity.

Changes in effective useful energy demand compared to 2008 that result either from the use of alternative application technologies (e.g. a building stock of higher thermal quality or

[67] Useful energy U is defined as the portion of final energy which is actually available after final conversion to the consumer for the respective use. In final conversion, electricity becomes for instance light, mechanical energy or heat. The effective useful energy used here considers efficiency factors of application technologies.

lightweight vehicles) or from changes in life styles and behaviour ($\Delta a_{w,t}$) are calculated according to equation (2):

(2) $$\Delta a_{w,t} = \frac{s_{w,2008} * u_{w,2008}}{100} - \frac{s_{w,t} * u_{w,t}}{100} = 100 - \frac{s_{w,t} * u_{w,t}}{100}$$

A reduction in final energy demand could also result from an improvement in final energy efficiency. Changes in final energy efficiency ($\Delta f_{w,t}$) as for example a more efficient heating system that add to the changes in energy services and useful energy intensity ($\Delta a_{w,t}$) are calculated as in equation (3). Based on equation (1) $\Delta f_{w,t}$ can be defined as

(3) $$\Delta f_{w,t} = \frac{s_{w,2008} * u_{w,2008} * f_{w,2008}}{10{,}000} - \frac{s_{w,t} * u_{w,t} * f_{w,t}}{10{,}000} - \Delta a_{w,t} = F_{2008,t} - F_{w,t} - \Delta a_{w,t}$$

Based on $\Delta a_{w,t}$ and $\Delta f_{w,t}$ remaining final energy demand in a given year can be expressed for each technology wedge as presented in equation (4):

(4) $$F_{w,t} = F_{w,2008} - \Delta a_{w,t} - \Delta f_{w,t} = 100 - \Delta a_{w,t} - \Delta f_{w,t}$$

The reduction in final energy demand by the technology wedge is the sum of $\Delta a_{w,t}$ and $\Delta f_{w,t}$.

From the methodological approach of transforming information from storylines into a likely path for services, useful energy intensity and final energy intensity expressed in indices one can then convert the results into changes in absolute final energy demand (in TJ) compared to 2008 (the last year for which official energy statistics are available) as well as into changes compared to the reference scenario developed in the project EnergyTransition.

Changes in final energy consumption have to be split up by energy sources in order to assess implications for the energy mix as well as associated emission reductions.

Based on this information the emission reductions compared to the reference scenario and 2008 can be calculated using emission factors from UNFCCC (2010). Changes in CO_2 emissions ($\Delta C_{w,t}$) are calculated by multiplying changes in absolute final energy consumption with the corresponding emission factor (c_i) for each energy source:

(5) $$\Delta C_{w,t} = \sum_i (c_i * \Delta F_{w,i,TJ,t}),$$ (TJ = Terajoule)

The common methodological approach for the areas mobility, buildings and manufacturing ensures the consistent integration of all technology wedges into the cascade of the energy system. A combination of technology wedges in order to achieve certain emission targets e.g. the emission target of the EU Energy and Climate Package then has to identify technology wedges that are additive. Combining e.g. a technology wedge "100% passive houses" in newly constructed buildings with a wedge "substitution of heating systems in conventional new buildings" is not feasible. In contrast "100% passive houses" in new construction and thermal improvement or substitution of heating systems in the building stock are fully additive.

For technology wedges in the area of energy supply a modified modelling approach is necessary as changes in the level of transformation input and in emissions are the result of changes in transformation output – which is driven by final energy demand – and in the fuel mix in the power and heat sector. Technology wedges that aim at the substitution of electricity and heat output from conventional plants by energy from low carbon technologies can be expressed by the following variables:

- $TO_{i,j}$ for transformation output from energy source *i* in plant type *j*,
- $TI_{i,j}$ for transformation input of energy source *i* in plant type *j*
- $e_{i,j}$ for transformation efficiency of plant type *j* using energy source *i* (amount of transformation output per transformation input, $e_{i,j}=TO_{i,j}/TI_{i,j}$).

The development of these central variables until 2020 is again expressed in indices (2008 = 100). Changes in transformation input depend on changes in transformation output on the one hand and changes in transformation efficiency on the other hand.

The central equation for technology wedges for energy supply hence can be written as

(6) $$TI_{w,i,j,t} = \frac{TO_{w,i,j,t}}{e_{w,i,j,t}} * 100$$

Equation (6) depicts the relationship of the three key variables. For a specific activity (*w*) transformation input of an energy source in a certain type of plant in a given year results from transformation output divided by transformation efficiency.

Although the modelling approach for energy supply deviates from the modelling of technology wedges in the other areas one can reconcile the common idea by interpreting final energy demand resulting from technology wedges in mobility, buildings and manufacturing as a proxy for *S*. Thus the potential or requirement for technology wedges in energy supply is not independent from activities in the sectors constituting final energy demand. The approach to relate the development of the central variables to the base year 2008 ensures that the relative changes versus 2008 can easily be translated into absolute changes versus 2008 as well as into absolute changes versus the reference scenario.

The extended technology wedges approach as applied in the project EnergyTransition extends the original method by Pacala and Socolow also with respect to economic analysis.

For the period until 2020 annual investment requirements[68] are estimated for each technology wedge and each storyline. In order to assess the domestic economic implications of the implementation of the technology wedges, investment costs are split up into sectoral investment shares as well as an assessment of the import share. The diffusion of technologies over time is defined by the storyline and can follow different paths: linear, exponential, stepwise or other.

For the analysis of economic effects from investments related to the implementation of a set of technology wedges, the investment cost for an "average" year split up by sectoral shares for each technology wedge are the starting point for the static input output analysis. Thus, the direct and indirect effects of these investments are calculated.

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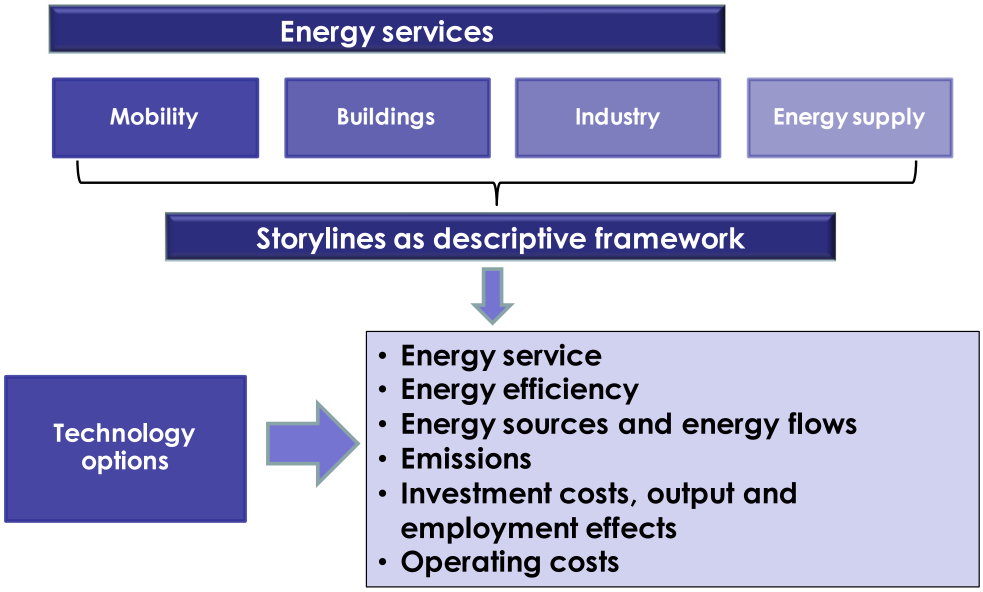
[68] Investment costs for the technology wedges are assessed as total costs as well as additional costs compared to a respective reference technology.

The economic analysis of the investment phase in the transition of the energy system is complemented by data for the operating phase. These data cover cost categories like maintenance, personnel, insurance, fuels etc. The development of operating costs mirrors again the diffusion path of technologies. For the operating phase "additional costs" are calculated, which are the difference between operating costs of the respective reference technology (e.g. a conventional building) and operating costs of the wedge technology (e.g. a passive house). For many technology wedges these additional costs will be negative because of the energy (cost) savings resulting from the application of more efficient technologies as compared to the reference case.[69]

EnergyTransition follows the steps as outlined in Figure 5 in order to operationalise the concept of energy services. The figure illustrates that both the effects in the energy system as well as economic effects are captured.

Figure 23: Diagram of the project EnergyTransition



Source: Own illustration.

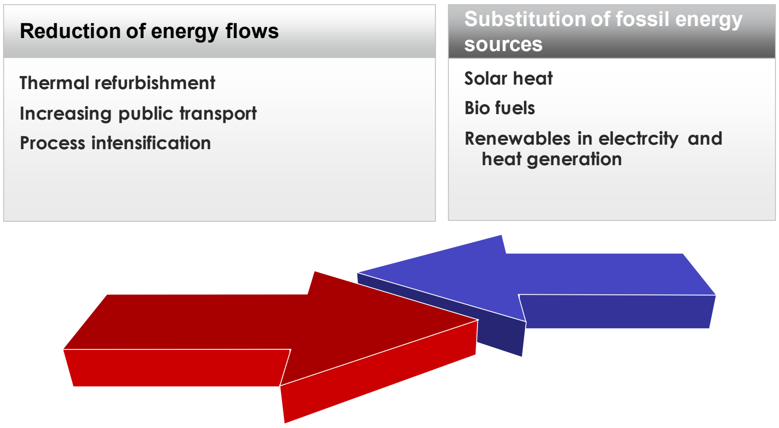
11.4 A catalogue of technology wedges for Austria

According to the concept of energy services as well as the common modelling approach described above concrete storylines and technology wedges for the areas mobility, buildings, manufacturing and supply of electricity and heat are developed.

[69] Apart from the estimates of macroeconomic effects of the investment phase as well as changes in operating costs of the technology wedges, a sample of technologies is selected for which a microeconomic cost appraisal is conducted. This method enables a better comparison of the cost impacts of the technology wedges considered, allowing an integrated analysis of the investment and operating phase. These results can be found in the full report of the project EnergyTransition.

Twenty-five storylines and technology wedges are analysed in detail in the project EnergyTransition. In principle two guidelines are available to translate the demand for energy services into lower energy flows or lower emission levels.

Figure 24: Guiding principles for emission reductions



Source: Own illustration.

The first guiding principle focuses more strongly on energy efficiency, whereas the second guideline stresses the emission reduction potential by reducing the emission intensity. Along these two principles the technology wedges are selected for the technology portfolios described in section 4.2.

With respect to the catalogue of technology wedges it has to be emphasised that the term "technology" also encompasses changes in energy services and resulting energy flows that follow from life style changes (e.g. change in place of residence in order to reduce daily travel distances). The catalogue illustrates well the systemic approach in EnergyTransition as one of the technology wedges in the sector electricity and heat supply is the result of lower energy demand in the sectors mobility, buildings and manufacturing. Finally it has to be mentioned, that for each sector feasible combinations of technology wedges are identified ensuring the additivity of changes in energy flows and emissions.

Figure 25: Catalogue of technology wedges

Mobility	Buildings	Industry	Energy supply
M1: Efficient land use	B1: Thermal refurbishment	P1: Energy demand industrial buildings	E1: Wind power
M2: Public transport	B2: Passiv House Standard	P2: Process-intensification	E2: Hydro plants
M3: Non-motorised transport	B3a: New heating systems	P3: Energy efficient engines	E3: Biogene CHP plants
M4: Alternative propulsion technologies	B3b: Solar heat	P4: Cogeneration heat and power	E4: Effects through reduced demand
M5: Freight transport	B4: Photovoltaic energy	P5: Substitution of fossil energy sources	
M6: Lightweight vehicles	B5: Energy efficient appliances	P6: Biomass for process heat	
M7: Bio fuels		P7: Solar heat	
M8: Relocation of fuel consumption			

Source: Own illustration.

11.4.1 Results for the technology wedges

Mobility

The energy service in mobility is the access to persons, goods and services needed for connecting important functions and amenities of daily life. According to this definition the energy service is sought not to decline over time. To simplify the measurability, energy service (S) is expressed by means of the variables vehicle kilometres, passenger kilometres and tonnekilometres. However, note that vehicle kilometres or passenger kilometres may be reduced or shifted in the storylines still leading to the same access to persons or goods with reduced energy consumption and reduced CO_2 emissions. In the transport sector energy and emission reduction potentials for different technology wedges are based on trends in motor vehicle stock and average mileage. Starting point is the recently observed transport performance in passenger transport (pkm) and freight transport (tkm) for the different individual passenger transport modes (motorised and non-motorised), public transport and freight transport (rail and road) when calculating emission reduction potentials (Käfer et al., 2009). Technology wedges in the storylines either refer to the total transport sector or only to segments of it (passenger or freight transport). For example alternative fuels concern both the passenger and freight transport sector, while for an enhancement of public transport only the passenger transport is relevant. Depending on the storyline and the segments considered energy indicators are calculated. They may thus refer only to these segments of overall transport.

The technology wedges aim at three major effects. First, transport performance (pkm or tkm) is reduced. Second, there is a shift between transport modes e.g. a shift from energy wasting modes like passenger cars to energy saving modes like bike and pedestrian. Third, changes come from efficiency gains because of improved motor technology and/or decreased mass of vehicles. These effects are described in the storylines for the different technology wedges.

Eight storylines and technology wedges are developed for the transport sector, calculating the emission reduction potential and the associated investment and operating cost effects. Table 1 summarises the emission reduction potentials of the mobility technology wedges, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 4: Key figures of technology wedges for mobility

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
M-1	Promotion of efficient transport saving land use	0.40	100	0.40	578	578	578	578	25	-205	25	-205
M-2	Improvement of public transport	0.46	76	0.35	13,167	13,167	10,018	10,018	581	278	442	212
M-3	Extension of non-motorised transport	0.42	83	0.35	648	648	540	540	2	-238	2	-198
M-4	Alternative propulsion technologies	0.15	100	0.15	5,435	2,295	5,435	2,295	119	-33	119	-33
M-5	Freight transport	0.40	100	0.40	396	396	396	396	n.a.*	n.a.*	n.a.*	n.a.*
M-6	Efficiency increase by lightweight construction of vehicles	0.50	88	0.44	36,062	0	31,734	0	4,956	-261	4,361	-230
M-7	Increase of biofuel additions	0.60	85	0.51	n.a.*	n.a.*	n.a.*	n.a.*	95	95	81	81
M-8	Relocation of fuel consumption	3.97	100	3.97	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*

Buildings

The building sector plays a central role in achieving the objectives of Austrian climate and energy policy. Its share in final energy consumption is almost 30%. Space heating and cooling consumed 314 PJ of final energy in 2008 *(Statistics Austria, 2009b)*. Energy and emission reduction potentials for different technology wedges described in the corresponding storylines are based on trends in energy demand for buildings. Starting point are data on energy demand in the building stock and in newly constructed buildings, existing heating systems as well as electricity consuming appliances.

As an approximation for services in the building sector surface area and energy demand per m² is taken (except for the technology wedge addressing efficiency potentials of electric appliances). The aim of the technology wedges is a reduction of the energy demand per service unit and thus an overall reduction of the energy demand of the building sector. This is to be accomplished by an improvement in the thermal quality of the building stock, a faster diffusion of passive houses in new construction, more efficient heating systems and a larger share of renewables including decentralised production of electricity, and finally savings in electricity demand through energy efficient appliances. For six technology wedges a detailed storyline is developed and underpinned with data.

- Thermal refurbishment of existing buildings according to Low Energy Standard
- Construction of new buildings according to Passive House Standard (PHS)
- Replacement of heating systems by more efficient ones based on renewables
- Intensified use of solar heat for space heating and hot water preparation.
- Increased power production from photovoltaics in zero energy buildings
- Energy optimised appliances, lighting and equipment

Table 2 summarises the emission reduction potentials of the building technology wedges, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 5: Key figures of technology wedges for buildings

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
B-1	Thermal refurbishment of existing buildings	1,18	100	1,18	55.682	38.985	55.682	38.985	302	-835	302	-835
B-2	Construction of new builidings according to Passive House Standard	0,28	100	0,28	47.051	7.457	47.007	7.450	74	-124	74	-124
B-3a	Replacement of heating systems by more efficient systems based on renewables	2,10	70	1,47	10.191	2.480	7.138	1.737	1.927	-421	1.350	-295
B-3b	Intensified use of solar heat for space heating and hot water preparation	0,35	70	0,25	14.294	11.447	10.006	8.013	669	-428	468	-300
B-4	Increased power production of builidings for own consumption	0,00	100	0,00	766	524	766	524	11	-50	11	-50
B-5	Energy optimised appliances, lighting and equipment	0,00	100	0,00	17.273	n.a.*	17.273	n.a.*	786	-527	786	-527

* not available.

Manufacturing

Despite an improvement in energy efficiency in the last decades energy demand from manufacturing in absolute terms has been increasing constantly. In 2008 the share of the production sector in total Austrian final energy consumption was 29%. Industry thus is the third area in the project EnergyTransition where a closer look at energy services is taken and where technological potentials for energy savings and emission reductions are analysed. The approach taken deviates from the more common sectoral analysis and starts from typical energy services in manufacturing. These are:

- Thermal energy services separated into three different temperature levels. The first temperature array is below 100°C, the second is between 100°C and 400°C and the third is above 400°C. Based on the Austrian Useful Energy Balances thermal energy services can be found in the categories space heating, steam production, industrial furnaces, drying and warm water supply.

- Mechanical energy services cover the provision of mechanical and kinetic energy. They are provided by engines which transform thermal, chemical or electrical energy into mechanical or kinetic energy. Generally production sectors have a considerable and increasing share of this service because of rising automation of technical processes. According to the Austrian Useful Energy Balances the useful energy categories stationary engines and traction belong to the mechanical energy services.
- Specific electrical energy services can only be provided by electricity. Energy services are provided by transforming electricity into other forms of energy like radiation (lighting). In this context, electricity is mainly used for illumination and electronics. The overall amount for this service shows no significant increase in the last years.
- Electrochemical energy services refer to electricity as part of a chemical reaction. Without this energy input the reaction would either not happen or in an uneconomic span of time.

Based on their technical potential eight storylines and technology wedges are developed with a time horizon until 2020. Table 3 summarises the emission reduction potentials of the technology wedges for industry, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 6: Key figures of technology wedges for manufacturing

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
P-1	Energy demand for industrial buildings	0,25	100	0,25	1.577	1.577	1.577	1.577	n.a.*	-171	n.a.*	-171
P-2	Process intensification and process integration	1,49	100	1,49	2.217	2.217	2.217	2.217	n.a.*	-739	n.a.*	-739
P-3	Energy efficient engines	0,06	88	0,05	704	704	616	616	n.a.*	-350	n.a.*	-306
P-4	Combined heat and power	-0,21	94	-0,20	331	319	312	301	44	-108	42	-102
P-5	Substitution of fossil energy sources with high emission-coefficients	0,84	67	0,56	65	-22	43	-15	423	-73	282	-49
P-6	Biomass for process heat	0,61	85	0,52	386	352	327	298	58	-143	49	-121
P-7	Solar thermal energy for process-heat and space heating	0,25	100	0,25	1.232	1.221	1.232	1.221	9	-72	9	-72

* not available.

Electricity and heat supply

Electricity and heat demand and hence transformation output from energy generation plants has been constantly rising in Austria. Fossil fuels still account for a large part in Austrian energy generation. The primary goal is therefore to develop technology wedges for reducing emissions from electricity and heat supply.

Emission reduction potentials in the energy sector generally include a shift to renewables or fossil fuels with lower emission factors and efficiency improvements, e.g. by the employment of co-generation plants instead of stand-alone technologies (see e.g. Öko-Institut – Prognos, 2009, Pacala – Socolow, 2004). Based on their technical potential in Austria for the power sector the following technology wedges are developed:

- a substitution of fossil electricity generation by wind power;
- a substitution of fossil electricity generation by run-off river plants;
- a substitution of coal based electricity generation and gas based heat generation by biomass and biogas based micro CHPs;
- a reduction in electricity and heat generation through reduced demand.

Table 4 summarises the emission reduction potentials of technology wedges for the sector electricity and heat supply, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) until 2020. In addition, impacts on operating costs are depicted.

Table 7: Key figures of technology wedges for energy supply

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
E-1	Substitution of fossil electricity generation by wind power	1.00	100	1.00	965	965	965	965	25	-43	25	-43
E-2	Substitution of fossil electricity generation by run-of-river hydro plants	1.00	100	1.00	1,044	1,044	1,044	1,044	26	-43	26	-43
E-3	Substitution of coal based electricity generation and gas based heat generation by biomann and biogas CHPs	1.00	100	1.00	738	738	738	738	117	-19	117	-19
E-4	Reduction in electricity and heat generation through reduced demand				n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*

* not available.

11.4.2 Technology wedge portfolios for the reduction triangle

Technology wedges filling the reduction triangle (see chapter 3) can be grouped into two categories:

- "efficiency wedges" and
- "fuel shift wedges".

"Efficiency wedges" are characterised by CO_2 savings resulting from lower final energy demand or from lower transformation input. Technology wedges achieving these reductions in energy consuming sectors (in this project: mobility, buildings and manufacturing) can originate either by a reduction of (redundant) energy services or by a decline in useful energy intensity (useful energy by service) or final energy intensity (final energy by useful energy)[70]. For electricity and heat generation, efficiency wedges imply a reduction in transformation input through an improvement in transformation efficiency.

"Fuel shift wedges" describe CO_2 emission reductions resulting from a shift to fuels with lower carbon content, e.g. an intensified use of renewables or a substitution of coal and oil by gas. Technology wedges can either concentrate on one of the two options or represent a combination of both, for example if coal based electricity generation is substituted by biomass based cogeneration. Given the uncertainty of the reference path – i.e. a potentially higher or lower effective reduction requirement in 2020 – it has to be emphasised that other combinations of technology wedges could also be implemented to comply with a higher/lower reduction target compared to the reference path.

Filling the reduction triangle can either have a stronger focus on "efficiency wedges" or on "fuel shift wedges". In the project EnergyTransition we present two different technology wedge portfolios are analysed, one focusing primarily on energy efficiency and one focusing mainly on changes in the fuel mix. The economic implications for each portfolio are analysed in an input-output setting.[71]

A technology wedge portfolio focusing on energy efficiency

This section presents a combination of technology wedges with a focus on energy efficiency. Hence, technology wedges from the areas mobility, buildings and manufacturing and their effects on the supply of electricity and heat are analysed. Table 5 presents the 18 technology wedges[72] considered to fill the reduction triangle and achieve an emission reduction of 14 million t CO_2 in 2020.

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[70] This includes the elimination of energy services (e.g. in terms of person kilometres but not the access to goods and persons) just as well as innovations that improve the efficiency of transformation and application technologies.

[71] The full report of the project EnergyTransition gives details on both technology wedge portfolios. Here a focus is given on the efficiency wedge portfolio.

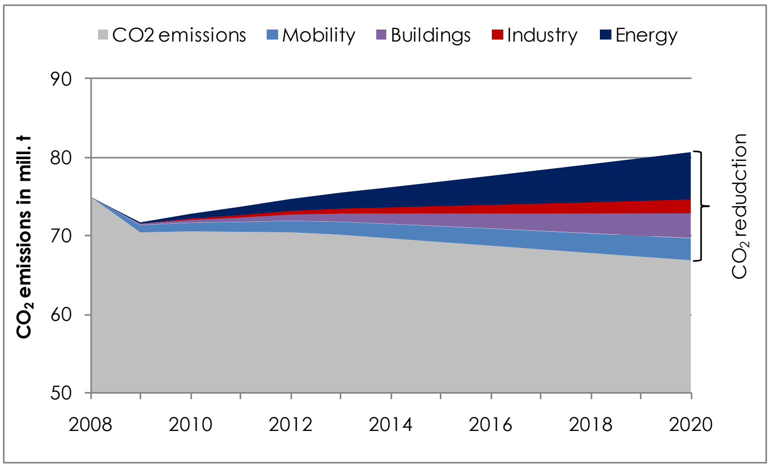
[72] The additivity of wedges is ensured.

Table 8: Technology wedge combination for the efficiency wedge portfolio

Technology wedge	
M-1	Promotion of efficient transport saving land use
M-2	Improvement of public transport
M-3	Extension of non-motorised transport
M-4	Alternative propulsion technologies
M-5	Freight transport
M-6	Efficiency increase by lightweight construction of vehicles
M-8	Relocation of fuel consumption
B-1	Thermal refurbishment of existing buildings
B-2	Construction of new buildings according to Passive House Standard
B-3a	Replacement of heating systems by more efficient systems based on renewables
B-3b	Solar heat for space heating and hot water preperation
B-4	Increased power production of buildings for own consumption
B-5	Energy optimised appliances, lighting and equipment
P-1	Energy demand for industrial buildings
P-2	Process intensification and process integration
P-3	Energy efficient engines
P-4	Combined heat and power
E-4	Reduction in electricity and heat generation through reduced demand

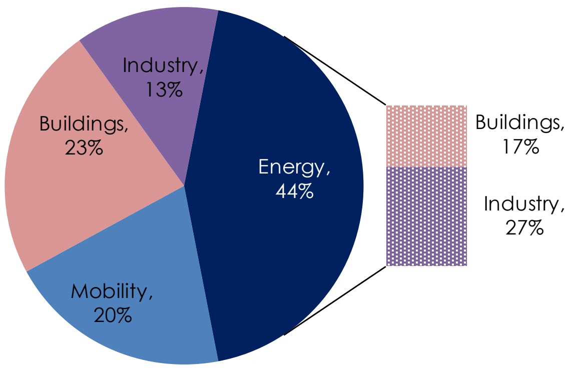
In Figure 8 the emission reductions are aggregated by sector and contrasted with the emission path of the reference scenario. Emission reductions from the mobility sector are 2.8 million t CO_2 in 2020. The technology wedges in the building sector achieve reductions of 3.2 million t CO_2 in 2020 compared to the EnergyTransition reference scenario. Emission reductions in the manufacturing sector amount to 1.8 million t in 2020 in this technology wedge portfolio. The largest emission reduction – 6 million t CO_2 in 2020 – is achieved by the energy sector. It has to be emphasised, however, that this emission reduction is exclusively the result of the lower heat and electricity demand resulting from the other sectors' efforts. A simple comparison of emission reductions by sector neglects this interrelationship of different levels in the energy cascade as explicitly considered in the project EnergyTransition (see Figure 9). The figure has to be interpreted as rough estimation. The emission effects from lower electricity and heat demand depend on the assumption which technologies and fuels are reduced for electricity and heat generation. Furthermore the additional electricity consumption in mobility is neglected.

Figure 26: Technology wedge portfolio focusing on energy efficiency compared to reference scenario



Source: Own calculations.

Figure 27: Sectoral emission reduction shares in the efficiency portfolio in 2020



Source: Own calculations.

The overall effects of the energy efficiency portfolio focusing on energy flows and emission reductions by energy source are illustrated in Table 6. Energy flows from final energy consumption and from transformation input in 2020 are 200 PJ lower than in the reference path. Oil use is reduced by almost 80 PJ, gas by 63 PJ. Coal contributes 45 PJ which translates into a relative reduction of almost 50% compared to the reference path. By reducing final demand the energy efficiency portfolio has an effect on all energy sources, thus also energy flows from renewables are slightly lower (2.8%) than in the reference scenario. The change in renewable has no relevance for the emission reduction of 14 million t CO_2.

Table 9: Change in energy flows and emission reduction by energy source – energy efficiency portfolio

Energy source	Final Energy Consumption and Transformation Input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	50.8	-45.4	-47.2	8.53	4.99	-4.4	-46.8
Oil	456.8	417.9	-79.2	-15.9	35.44	32.83	-5.7	-14.9
Gas	289.2	255.5	-63.2	-19.8	15.90	14.05	-3.5	-19.8
Renewables	380.5	418.6	-11.9	-2.8	2.87	3.13	0.0	0.0
Total	1,213.8	1,142.8	-199.6	-12.1	62.7	55.0	-13.6	-18.7

Source: Own calculations.

A similar approach as for the technology wedge portfolio focusing on energy efficiency is taken for the second technology portfolio focusing on low carbon fuels. This means that primarily technology wedges addressing a fuel shift in energy supply or in energy demand are considered. In order to fill the reduction triangle, however, some technology wedges that focus exclusively on improvements in energy efficiency need to be included.

For this technology portfolio only the overall changes in energy flows and emission are presented here[73]. Table 7 summarises the overall effects of the low carbon portfolio focusing on energy flows and emission reductions by energy source. Energy flows from final energy consumption and from transformation input in 2020 are 140 PJ lower than in the reference path. The low carbon portfolio thus yields lower changes in energy flows than the energy efficiency portfolio, although both portfolios achieve an emission reduction of 14 million t CO_2. Oil use is reduced by almost 100 PJ, gas by 47 PJ. Coal contributes approximately 40 PJ which is somewhat less than in the energy efficiency portfolio. The largest difference to the energy efficiency portfolio results for renewables, which showed a slight decrease in the efficiency portfolio compared to the reference path. In the low carbon portfolio energy flows from renewables exceed the reference scenario by 45 PJ (10%). Thus, in terms of producing not only emissions but also energy flows – irrespective of the energy sources – efficiency portfolios generate superior results.

[73] For further details on this technology wedge portfolio see the full report on the project EnergyTransition.

Table 10: Change in energy flows and emission reduction by energy source – low carbon portfolio

Energy source	Final Energy Consumption and Transformation Input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	55.5	-40.6	-42.3	8.53	5.45	-3.9	-41.9
Oil	456.8	399.9	-97.3	-19.6	35.44	31.35	-7.2	-18.7
Gas	289.2	272.0	-46.7	-14.7	15.90	14.96	-2.6	-14.7
Renewables	380.5	475.7	45.2	10.5	2.87	3.13	0.0	0.0
Total	1,213.8	1,203.0	-139.4	-8.4	62.7	54.9	-13.7	-18.9

Source: Own calculations.

11.5 Economic analysis

For the estimation of output and employment effects a multiplier analysis is conducted. These calculations show which demand effects follow an investment activity in a certain sector. The multiplier analysis represents a static input-output approach using the input-output table by ÖNACE categories as published by Statistics Austria (2009c).

For the economic analysis investment and operating costs for each technology wedge were compiled in a bottom up approach. The economic analysis within the project EnergyTransition comprises on the one hand economic effects of the investment phase for the two technology wedge portfolios based on an input output analysis. This is complemented by an illustration of the development of operating costs. On the other hand, for selected technology wedges a microeconomic cost appraisal is conducted[74] that – contrary to the macro perspective of the input output analysis – puts the focus on micro economic aspects.

In the following, the results for the technology wedge portfolio focusing on energy efficiency are presented. With respect to the input-output results these are comparable to the second technology wedge portfolio focusing on fuel shift, for which the results can be found in the full report to the project EnergyTransition.

11.5.1 Input-output effects of the efficiency technology wedge portfolio

For the period until 2020 annual investment requirements for each technology wedge are compiled in a bottom up approach. Total investment costs as well as additional investment costs are assessed[75]. Additional investment costs apply to cost differences compared to a

[74] The micro economic cost analysis can be found in the respective chapters on technology wedges for mobility, buildings, industry and supply of electricity and heat in the full report of the project EnergyTransition.

[75] For some technology wedges the assessment of investment cost was not possible and thus not all technology wedges could be considered for the quantification of the output and employment effects.

respective reference technology. In order to assess the domestic economic implications of the implementation of technology wedges, investment costs are split up into sectoral investment shares. The diffusion of technologies over time is defined by the storylines and can follow different paths: linear, exponential, stepwise or other.

The input-output analysis is based on the additional investment costs of the technology wedges included in the portfolio. The use of additional investment costs ensures that the effects induced by a transformation of the energy system along the energy cascade are quantified. That is, only the employment and output effects of the technology wedges that go beyond investments required for a reference technology or a reference path are calculated. As in terms of emission reductions for the portfolios only the combined wedges' reduction potential is taken into account. For the economic impacts, correspondingly, only the additional effort for transforming the energy system towards increased sustainability is considered. The assessment of the employment and output effects is based on an average annual investment for the period 2009 to 2020 as well as for investment in 2020.

Technology wedges chosen for the efficiency portfolio are listed in Table 8, showing the additional investment costs required for each wedge on average over the twelve-year period from 2009 to 2020 as well as in 2020. The additional investment costs follow the diffusion path of the technologies described in the storylines and are based on the feasible combination of technology wedges in the sectoral analysis to ensure the additivity of the wedges. The highest share in additional investment costs accrues to the building sector.

Table 11: Technology wedges and additional investment in the energy efficiency portfolio

	Technology wedge	Additional investment		
		Average 2009/2020		2020
		in million €	in %	in million €
M-1	Promotion of efficient transport sav ing land use	48,1	0,8	48,1
M-2	Improv ement of public transport	834,9	13,3	834,9
M-3	Extension of non-motorised transport	45,0	0,7	45,0
M-4	Alternativ e propulsion technologies	191,3	3,0	582,9
M-5	Freight transport	33,0	0,5	33,0
M-6	Efficiency increase by lightweight construction of v ehicles	n.a.	n.a.	n.a
M-8	Relocation of fuel consumption	n.a.	n.a.	n.a
B-1	Thermal refurbishment of existing buildings	3.248,8	51,8	4.826,0
B-2	Construction of new buildings according to Passiv e House Standard	621,4	9,9	1.085,7
B-3a	Replacement of heating systems by more efficient systems	144,7	2,3	188,9
B-3b	Solar heat for space heating and hot water preperation	667,8	10,6	541,2
B-4	Increased power production of buildings for own consumption	43,7	0,7	70,2
B-5	Energy optimised appliances, lighting and equipment	0,0	0,0	0,0
P-1	Energy demand for industrial buildings	131,5	2,1	143,4
P-2	Process intensification and process integration	184,8	2,9	201,6
P-3	Energy efficient engines	51,0	0,8	55,7
P-4	Combined heat and power	26,0	0,4	28,4
E-4	Reduction in electricity and heat generation through reduced demand	0,0	0,0	0,0
Total		**6.271,9**	**100,0**	**8.685,1**

Source: Own calculations.

Additional costs for the six technology wedges in the area buildings amount to 6,712 million € in 2020; average annual investment costs of these technology wedges for the period 2009 to 2020 are 4,726 million € respectively. Technology wedges for mobility have the second largest share in total additional investment costs amounting to 1,544 million € in 2020 and to an average of 1,152 million € p.a. for the period 2009 to 2020 respectively. Additional investments for the four technology wedges in manufacturing are 429 million € in 2020 and on average 393 million € p.a. over the twelve years respectively. For energy supply only Technology Wedge E-4 which comprises emission savings due to reduced final energy demand is considered in this technology wedge portfolio. For this technology wedge investment costs are zero as all investment costs are accounted for in the areas mobility, buildings and manufacturing.

The economic effects of the technology wedge portfolio focusing on energy efficiency are summarised in Table 9. On average over the period 2009 to 2020, the efficiency portfolio generates output effects of 9,498 million € and value added effects of 4,633 million €. In terms of employment 80,469 jobs and 76,129 full time equivalents (FTE) are related to the implementation of this technology wedge portfolio. The output multiplier and the value added multiplier for the efficiency portfolio are 1.51 and 0.74 respectively. This means that with each million € of additional investment output increases by 1.51 million €, value added increases by 0.74 million €, which is related to the protection or creation of approximately 13 jobs.

In 2020 output effects of 14,115 million € and value added effects of 5,955 million € are generated. Employment effects are 106,932 jobs or 99,512 FTE respectively. The higher output and employment effects compared to the twelve-year average mainly result from the higher additional investment costs in 2020.

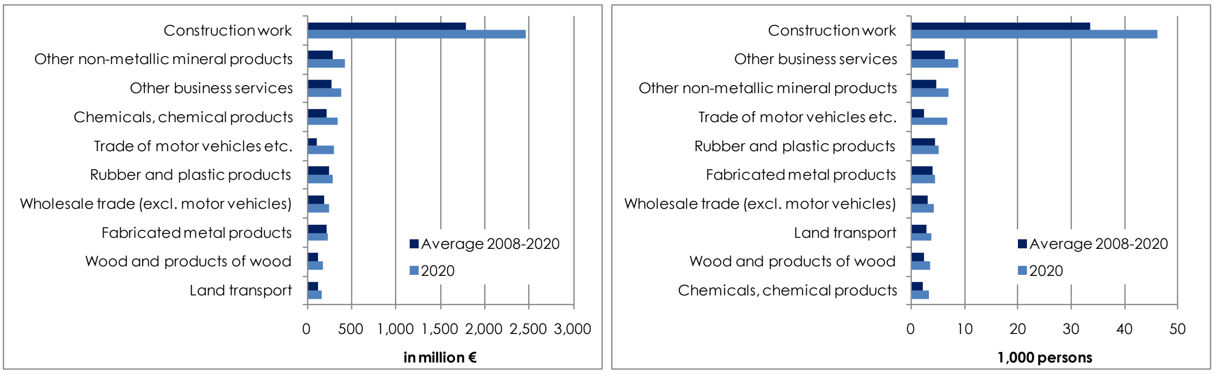
Table 9: Economic effects of the energy efficiency portfolio

		Average	2020
Output effects	mill. €	9,498	14,115
Value added effects	mill. €	4,633	5,955
Employment effcts	persons	80,469	106,932
	FTE [1]	76,129	99,512

Source: Own calculations. – [1] FTE stands for full time equivalents.

Figure 10 shows the sectoral effects of additional investment in the efficiency portfolio. Due to the large share in total additional investment the highest sectoral effects are found in the sector construction work. In addition, high value added effects can be observed for other non-metallic minerals, chemicals and chemical products and for other business services. Besides the employment effects in construction work, high employment effects result for the sectors other business services and for other non-metallic minerals[76].

Figure 28: Highest sectoral value added effects (left) and highest sectoral employment effects (right) in the efficiency portfolio



Source: Own calculations.

11.5.2 Operating costs in the efficiency technology wedge portfolio

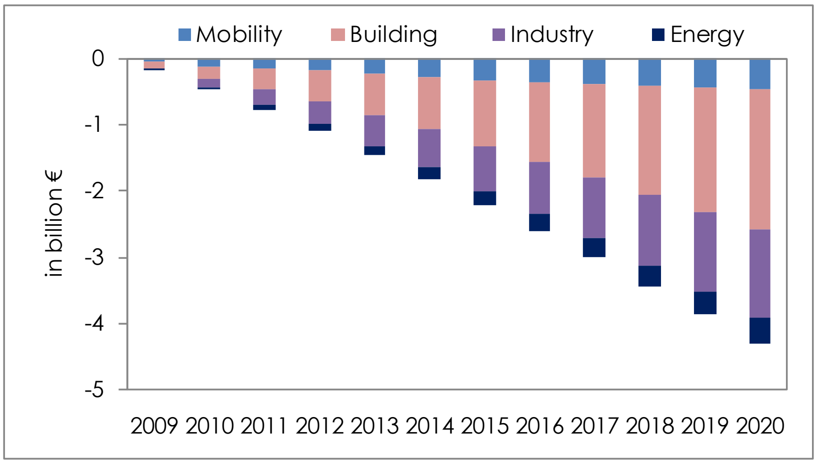
The implementation of the technology wedge portfolio described above has also considerable effects in the operating phase. In order to illustrate the difference in operating

[76] The results for the second technology wedge portfolio can be found in the full report to the project EnergyTransition.

costs between the technology wedges and respective reference technologies a similar approach is followed as for the investment phase: Total operating costs of the technology wedges are contrasted with respective additional operating costs in order to illustrate the effect of the technology wedge. Negative additional operating costs hence refer to cost savings compared to a reference technology. In contrast to annual investment, operating costs as well as cost savings increase over time in line with the diffusion path of the investment and are thus cumulative.

Figure 11 illustrates the development of operating cost savings for the energy efficiency portfolio. Cost savings are quantified for the areas mobility, buildings, manufacturing and electricity and heat supply[77]. In line with the large contribution of the building sector to investments and emission reductions in this portfolio operating cost savings are highest in the building sector reflecting the significant energy savings. Figure 11 clearly illustrates the cumulative character of the operating cost effect. In 2020 operating cost savings amount to -4.3 billion €.

Figure 29: Operating cost savings of the energy efficiency portfolio



Source: Own calculations.

In general technology wedges realise operating cost savings compared to the respective reference technologies. A simple comparison between technology wedges with respect to the extent of cost savings, however, is not sensible as the simple focus on operating costs neglects the capital costs of the technology wedges and related relevant parameters like the service life of the technologies[78]. This perspective would be insufficient to

[77] For some technology wedges a quantification of operating cost savings was not possible. Cost calculations for electricity and heat supply include savings in fuel costs only.

[78] A separate analysis for a sample of technology wedges implements these aspects in a microeconomic cost appraisal, that can be found in the full report of the project EnergyTransition.

comprehensively assess technological options as the focus on investment costs and payback times without accounting for effects over the whole service life[79].

11.6 Perspectives for 2050

The long term GHG reduction target in order to limit the risk of a global temperature increase of more than 2°C requires a further scaling up of the proposed measures and technologies as described in the storylines as well as continuous technological and social innovations. The long term perspectives until 2050 connect to the detailed recommendations for emission reductions until 2020 in the analysed areas mobility, buildings, industry and energy supply.

The decarbonisation of transport – seen from today's perspective – is likely to work along the very same technology wedges as given in the previous section for the 2020 time horizon, albeit at a different relative weight. Technology wedges directed most closely at the services themselves, such as spatial planning will gain in importance over time – if it is initiated early enough to enfold its long term impact. Given improved spatial planning, public transport and non-motorised transport can serve a broader share of the population, thus enhancing the impact of these two technology wedges in the long term. Vehicle efficiency already crucial in quantitative terms up to 2020 could be substantially exploited further. The same holds for lightweight technology.

In the building sector new design and technology concepts have to be implemented which meet the necessary requirements of low energy demand. The adoption of new technologies will go hand in hand with the implementation of enforced legal standards and codes regarding energy efficiency in the building sector. Energy demand of the new generation of buildings will be nearly zero, as it is already required by the new European Directive on Energy Performance in Buildings (European Commission, 2010a) and obligatory for all new constructed buildings in Europe after 2020. The future design of buildings is going towards the development and implementation of "zero energy" and "plus energy" buildings.

Zero Energy Buildings are based on the following principles: reduce energy demand, use energy gains and avoid installing active heating and cooling systems by implementing proper passive construction measures (e.g. shading to avoid overheating of buildings in summer). Any remaining (very low) demand for heating shall be supplied through low-temperature systems (heat pumps, solar heating & cooling – all in all "flameless" technologies instead of heating boilers in buildings, except in the case of co-generation systems) or use efficient ventilation and air conditioning systems (HVAC) and highly efficient equipment and lighting. Zero Energy Buildings differ to Zero Net Energy Buildings and Zero Carbon Buildings. Zero Net Energy Buildings are neutral over a year, they deliver as much energy to the supply grids as they use from the grids. Zero Carbon Buildings are carbon neutral or positive and produce enough CO_2 free energy to supply themselves with energy over the year (IEA, 2008).

[79] The results for the technology wedge portfolio focusing on low carbon technologies can be found in the full report to the project EnergyTransition.

Plus-Energy Houses comply with the criteria of PHS and are characterised by active power supply and energy-saving equipment used by tenants/owners. The buildings are producing annually more energy than they require for own consumption. Roof and façades are actively used for e.g. photovoltaic plants. The solar power plant is feeding excess electricity into the local grid, or even charging batteries of electrical vehicles. Simultaneously these buildings become energy suppliers, e.g. for solar heating and cooling, photovoltaics etc.

The perspectives with respect to energy demand and emission of GHGs from industry in Austria in 2050 will largely depend on the following developments:

- economic development (GDP growth)
- industry structure (globalisation)
- development in other sectors (passive house instead of conventional houses, lightweight cars instead of SUVs, more electronics in all products, new communication technologies, etc.)
- specific energy input (improvements in energy efficiency)
- change in the mix of energy sources (driven by prices, regulations, availability, technological progress, etc.)

It can be assumed that the technology wedges defined for the period till 2020 will be valid until 2050. Radical changes are not ruled out, but unpredictable. The relative potential to contribute to emission reductions stems from various technical options:

- Cogeneration of low-temperature heat and power in medium sized units which leads to reduced energy demand mainly in the energy supply sector.
- Passive houses and energy-plus buildings for office buildings, production halls and storages resulting in an almost complete avoidance of room heating.
- Process intensification through new technologies, heat integration and process optimization for production processes in all sectors.
- Shift to renewable energy (solar process heat, biomass heating systems, biogas from waste, PV, etc.) mainly for low temperature processes, in selected cases with cogeneration; biomass refinery concepts for the utilization of the whole plant in the food chain.
- Improved efficiency in electrical applications (drives, cooling, etc.).
- Material substitution including a shift from steel to polymeric materials, concrete to wooden structures and more light materials in general.
- CCS technologies will still play a minor role in industries.

For the energy supply sector there are basically two fundamentally different approaches for developing perspectives: the supply focused approach and the demand focused approach. Only an integrated approach that takes into account the interrelation between supply and demand is, however, capable of providing constructive insights into the potential futures of our energy systems.

Forecasting energy supply by looking into the future via the rear mirror of past trends is not viable. Instead of the future based on past developments a methodology of a backcasting from potential viable futures to the present should be applied.

The challenge in the project EnergyTransition lies in the proposition of concrete technological changes in the Austrian energy system until 2020 for the areas mentioned above along with alternative supply structures of energy that do not contradict a more long term perspective of the overall energy system in 2050. For energy supply this means to think of changes in infrastructure and fuel shifts in electricity and heat generation until 2020 that will not turn out as technological lock-ins or prove as sunk costs. Thus a guiding principle for the proposed technological changes in energy supply up to 2020 was to have the longer 2050 perspective in mind.

The expected structures of the energy system in about four decades determine the next steps to put the current energy system on a viable transformation path. The following guidelines for policymakers, companies and consumers can be derived:

(1) Viable energy systems will require a multiplication of current energy productivities.

(2) Higher energy productivity is coupled with higher energy quality. This mean, for example, there will be a lower demand for low temperature heat but a higher demand for electric appliances, electronics and motors.

(3) The energy supply mix needs to adjust to shifts in demand. The expected demand shifts in the quality of energy need to be reflected by a matching supply mix with a higher share of high exergy energy such as electricity and a lower share of low exergy energy as low temperature heat.

(4) The energy supply structure will become more decentralised.

(5) Primary energy is to be used and reused in a cascadic structure. Some feed stocks as crude oil but also biomass can be transformed both into materials (e.g. for producing polymers and other structures) and energy (e.g. heat and electricity). These feed stocks need to be used in the full cascade of their potential use, that priority is given to the use as materials which should be recycled and only afterwards used as input for the energy system.

Materials and material technologies will play an increasingly important role in the energy system, both in terms of significantly enhanced energy efficiency for specific energy services but also in terms of energy supply related to renewable energy technologies including the entire energy transformation chain. In terms of the longer-term perspective an important shift is envisaged in the role of materials in technology systems from simply being structural or functional materials for specific parts and components to a significantly stronger service oriented role, which aims at the enhancement of systems efficiency, effectiveness and functionality providing higher quality services. In other words, next generation materials will be developed and adapted to specific needs and functionalities with a much stronger focus on the optimisation of the systems functionality and performance. Among all material classes, polymeric materials, composites and hybrid materials offer the largest potential for tailoring novel materials towards specific multi-functional property and performance profiles.

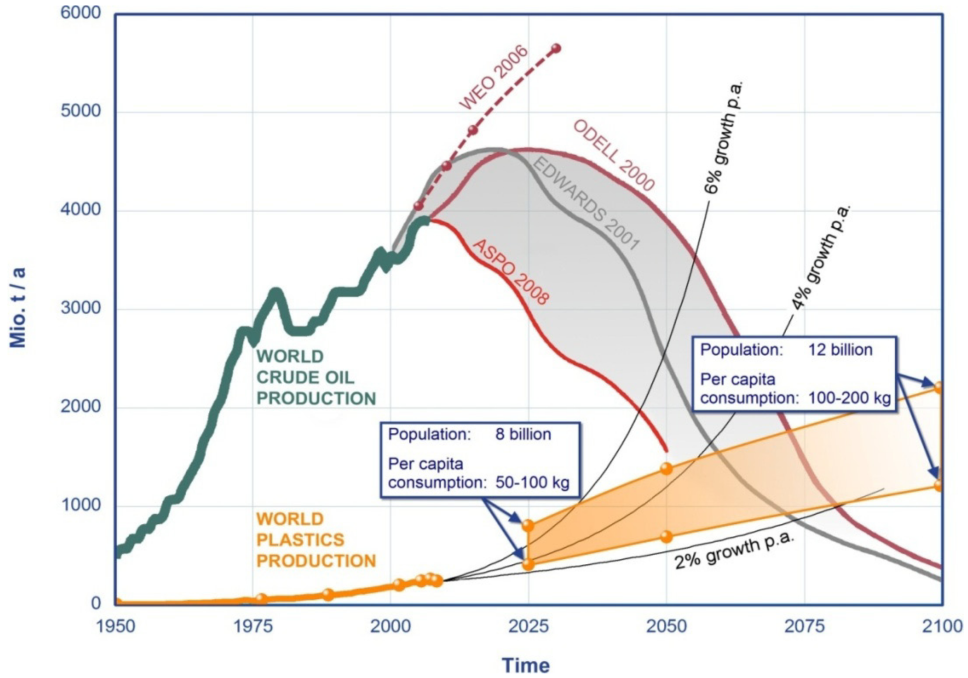
As to material performance improvements, it becomes increasingly apparent, that they play an important role in the overall energy efficiency improvements in existing technologies and applications. The most significant improvements in the future are again expected in the field of polymeric materials and advanced composites and hybrid materials. There are several key fields of energy technology functions in which materials play a major role in terms of improved energy efficiency and a higher quality of energy services. These include:

- In the field of enhanced energy efficiency:
    - Materials for thermal functions such as required in heating and cooling of buildings and the living environment.
    - Materials for structural and primarily mechanical functions in buildings and vehicles aiming at light-weight and ultra-light-weight constructions and designs.
- In the field of energy generation (i.e., harvesting of renewable energies) and energy transformation and transportation:
    - Materials for direct solar technologies (solar-thermal and solar-electrical),
    - Materials for indirect solar technologies (e.g., wind energy harvesting with wind mills of various designs and size scales from micro- to large-scale; high voltage DC cables for efficient electric energy transportation),
    - Materials for hydropower and wave-power energy generation, particularly also of small size scales (small and micro-turbines).
- In the field of energy storage:
    - Materials for batteries and capacitors of various size scales (e.g., large capacity light-weight batteries of high energy density for vehicles),
    - Materials for solar-chemical conversion technologies (e.g., conversion of atmospheric CO_2 into hydrocarbons or alcohols; electrolysis of water to produce hydrogen)
    - Thermal storage materials with significantly enhanced energy density compared to current water based sensible heat stores.

Considering the rising importance of polymers, the aspect of sufficient raw material availability for the next decades has been addressed most recently by Lang and Kicker (2010). Currently polymeric materials and plastics are produced predominantly from crude oil, consuming about 5% of the overall crude oil production annually.

Figure 12 combines various lower and upper bound scenarios in terms of future oil production and future plastics growth in a single chart. As "official" plastics growth scenarios up to 2050 by industry associations and alike are difficult to obtain, two approaches where followed in Figure 12. One approach is based on the crude oil need for current production volumes which were assumed to grow by rates in the range from 2 to 6 % p.a. (black solid lines in the illustration). The other is based on assumptions for population growth (8 billion in 2025, 12 billion in 2100), superimposed with lower/upper bound assumptions for the annual average per capita plastics consumption (50 and 100 kg per capita and year in 2025; 100 and 200 kg per capita and year in 2100).

Figure 30: Comparison of plastics growth and peak-oil scenarios



Source: Lang – Kicker (2010).

Based on such scenarios as illustrated in Figure 12 combined with considerations of technology and innovation opportunities for the fossil fuel and the plastics industry, in Lang (2006, 2010) it is concluded that the interests of the oil and gas industry and the solar industry will converge. Among other reasons, this will be the case also in order to secure for a sufficient raw material supply for higher value-added products such as polymeric materials. After all, many oil/gas production companies are also directly or indirectly (via ownership) involved in the production of plastics. In addition, alternative raw material resources for the production of renewable resource based polymers either in terms of biomass or by proper conversion technologies utilizing atmospheric CO_2 to produce hydrocarbons (e.g., methane) or alcohols (e.g., methanol) and alike will become increasingly important by 2050.

11.7 Conclusions

- **A new look at the energy system**

The overall target for energy and climate policy is to stabilise global warming below 2° Celsius. This target cannot be reached en passent i.e. when we follow a business as usual path with few measures and minor technological changes. Rather this target means that a substantial restructuring of the energy system needs to start immediately focusing on a broad diffusion of available alternatives and concurrently increasing R&D.

Common analyses of the energy system put a strong focus on the availability of primary energy sources and energy generation. This perspective entices one to overlook changes on other levels of the energy system. A fundamental change in energy systems that is suitable to achieve the political targets with respect to climate change, however, requires a different perspective. Only an integrated view of the whole energy cascade and furthermore the end of the energy cascade, namely from energy services, as a starting point are preconditions for overcoming path dependencies. Energy services are the crucial element for this new understanding of the energy system as not the level of energy flows consumed is welfare relevant but the welfare generating energy service, i.e. comfortable room temperature, access to goods and persons.

- **Energy services for mobility, building, industry, the role of materials and energy supply**

The study EnergyTransition is a concrete application of a new, "energy service based" philosophy. From the energy service perspective three sectors are of central importance: mobility, buildings, industry. Energy services can be provided by a broad range of technologies. In EnergyTransition technology options are developed in storylines for technology wedges until 2020: Each technology wedge is defined as an option to reduce Austrian CO_2 emissions by a certain amount by 2020. For the areas mobility, buildings, industry and electricity and heat supply technology wedges were developed that follow the common EnergyTransition methodology. The role of new materials is explicitly addressed in the areas buildings and mobility. The result is a catalogue of technology wedges that can be used in order to meet the Austrian GHG reduction targets as defined by the EU Energy and Climate Package.

- **The challenge of the 2020 targets**

The analyses of technological options in the project EnergyTransition and the reduction requirements resulting from the reference scenario and the policy objectives show that the implementation of a comprehensive bundle of measures is necessary in order to fulfil the Austrian energy and climate targets. Besides targeting all different levels of the energy system and all sectors an immediate realisation of emission reduction measures is essential. The deployment of energy efficiency options is preferable to low carbon technologies as the former not only reduce emissions but also energy flows. The challenge in both cases is ensure additivity of measures as well as to use technology options that do not lead into technological lock-ins. That means that a perspective beyond 2020 needs to be kept in mind.

- **Economic effects: investment and operating phase**

The restructuring of the energy system requires considerable investment efforts. Investment in the transformation of the energy system translates into an economic stimulus with corresponding output and employment effects. Quantified are the effects of additional investment that is investment costs of a technology wedge exceeding those of a reference technology. Whereas the stimulus effect of investment to the transformation period of the energy system, cost savings in the operating phase prevail over the whole service life of the technology. In general technology wedges realise operating cost savings compared to the respective reference technologies. A simple comparison between technology wedges with respect to the extent of cost savings, however, is not sensible as the simple focus on operating costs neglects the capital costs of the technology wedges and related relevant parameters like the service life of the technologies[80]. This perspective would be as insufficient to comprehensively assess technological options as the focus on investment costs and payback times without accounting for effects over the whole service life.

- **Central role of the building sector**

The great challenge for the building sector is a high quality renovation of the existing building stock and an intensified increase of the renovation rate to an extent, which up to now has not been implemented. The highest necessity for renovation lies in the building stock of the post war period. A highly important aspect is energy awareness and a changed user behavior, together with a significant reduction of the energy demand of living. Future buildings are characterized by nearly zero and plus energy buildings, which increasingly will contribute to decentralised energy supply.

- **Political framework**

While climate targets are usually acknowledged by decisions makers the transformation of targets into actual actions seems to fail due to differing political and institutional barriers. For example it may be that the emission reduction options and the impact on greenhouse gas emissions are simply not known, that there is resistance due to different interests of stakeholders or that the overall energy system is not considered by scheduling policy measures. The strength of the EnergyTransition framework is that (1) all relevant reduction options in different sectors are considered and quantified, (2) that interferences between different options within a sector but also across sectors are considered and (3) that changes in energy demand due to reduction options are balanced with energy supply thus considering the entire energy system. (4) Reduction options are considered on each step of the energy cascade beginning with the energy service. Reduction options starting on this step of the energy cascade are most effective. The Energy Transition framework guarantees a more efficient scheduling and assessment of policy measures for decision makers thus increasing the possibility that climate policy meets its targets.

[80] A separate analysis for a sample of technology wedges implements these aspects in a microeconomic cost appraisal.

- **Long term perspectives – no technological lock in**

The 2020 emission reduction targets are an intermediate step towards the longer term perspective of de-carbonising the economy in order to limit global temperature rise to 2°C. When implementing measures for the required transition it is essential to keep this long term perspective in mind and avoid lock-in effects regarding technologies and associated infrastructure, social behavior and institutions. This long term perspective was also a guiding principle in developing the storylines for the technology options in EnergyTransition.

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