WIFO
ÖSTERREICHISCHES INSTITUT
FÜR WIRTSCHAFTSFORSCHUNG

WORKING PAPERS

Restructuring the Austrian Energy System: An Extended Technology Wedges Approach

Claudia Kettner, Daniela Kletzan-Slamanig, Angela Köppl, Stefan Schleicher (WIFO), Andrea Damm, Karl W. Steininger, Brigitte Wolkinger (Wegener Center), Hans Schnitzer, Michaela Titz (TUG-IPE), Heidemarie Artner, Andreas Karner (KWI)

385/2011

Restructuring the Austrian Energy System: An Extended Technology Wedges Approach

Claudia Kettner, Daniela Kletzan-Slamanig, Angela Köppl, Stefan Schleicher (WIFO), Andrea Damm, Karl W. Steininger, Brigitte Wolkinger (Wegener Center), Hans Schnitzer, Michaela Titz (TUG-IPE), Heidemarie Artner, Andreas Karner (KWI)

WIFO Working Papers, No. 385
February 2011

E-mail address: Claudia.Kettner@wifo.ac.at
2011/022/W/0

Medieninhaber (Verleger), Hersteller: Österreichisches Institut für Wirtschaftsforschung • 1030 Wien, Arsenal, Objekt 20 • Tel. (43 1) 798 26 01-0 • Fax (43 1) 798 93 86 • http://www.wifo.ac.at/ • Verlags- und Herstellungsort: Wien

Restructuring the Austrian Energy System: An extended technology wedges approach

Claudia Kettner[a,b], Daniela Kletzan-Slamanig[a], Angela Köppl[a], Stefan Schleicher[a], Andrea Damm[c], Karl Steininger[c], Brigitte Wolkinger[c], Hans Schnitzer[d], Michaela Titz[d], Heidemarie Artner[e], Andreas Karner[e]

Key words: climate and energy policy, energy services, technology options, input-output analysis

JEL codes: O13, Q54, Q55

Abstract

EU climate and energy policy defines ambitious objectives for the Member States requiring a fundamental change of energy systems. This paper suggests to base the analysis of restructuring options on energy services instead of energy flows. In order to provide the energy services in a sustainable way the guidelines "low energy – low carbon – low distance" should be used. This refers to an increase in energy efficiency, the reduction of fossil fuels and the reduction of (redundant) transport. An extended technology wedges approach is applied for Austria to illustrate emission reduction options through technological and behavioural changes. Two portfolios of technology wedges are quantified regarding their effects on energy flows and emissions as well as the economic impacts of investments required.

[a] Austrian Institute of Economic Research (WIFO)

[b] Corresponding author; Claudia Kettner, Austrian Institute of Economic Research (WIFO), Arsenal Objekt 20, A-1030 Vienna; claudia.kettner@wifo.at

[c] Wegener Center for Climate and Global Change, University of Graz

[d] Institute for Process and Particle Engineering, Graz University of Technology

[e] KWI Consultants GmbH

Introduction

The Energy and Climate Package of the European Commission (European Commission, 2008a, b) stipulates ambitious targets for the EU Member States. A reduction of greenhouse gas emissions, a higher share of renewable energy sources and a significant improvement of energy efficiency require a fundamental restructuring of existing energy systems, i.e. of current patterns of energy use and generation. This paper suggests to base the analysis of restructuring options on energy services instead of energy flows, as it is not the quantity of energy consumed by households and companies that is relevant for welfare but the energy services delivered. In general, three categories of energy services can be distinguished:

- 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 that are used for vehicles to satisfy mobility needs on the one hand and for stationary engines in households and companies on the other hand, and
- specific electric energy services for lighting, electronics and other appliances.

The volume of energy services is influenced by various factors including economic activity, income and individual preferences and mirrors economic welfare. The energy demand of households and companies for providing energy services depends on the application and transformation technologies used. In buildings e.g. the energy 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. In order to provide the desired energy services in an efficient and sustainable way the guidelines “low energy – low carbon – low distance” should be used. "Low energy" constitutes the first priority in a restructuring process and addresses activities to improve energy efficiency. "Low carbon" stands for a phase-out of fossil energy sources. This, however, can only be achieved in combination with significant energy efficiency improvements. "Low distance" is related to the local/regional availability of renewable energy sources and distributed generation as well as to the avoidance of redundant mobility e.g. by improved spatial planning, tele-commuting etc.

Modelling approach

Pacala and Socolow (2004), Socolow et al. (2004) show that a stabilisation of global greenhouse gas emissions[6] using existing technologies is possible within the next 50 years and that a broad diffusion of innovative technologies is required afterwards to reach the concentration goals. 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. Each of the technology categories – the so called stabilization wedges – can be implemented in the short term and has the potential to cut global carbon emissions by 1 Gt by 2054. 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 large scale climate-relevant research and development on the other hand.

In this paper the concept of stabilization wedges is taken as a starting point and extended with respect to technology options – so called technology wedges[7] – 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:

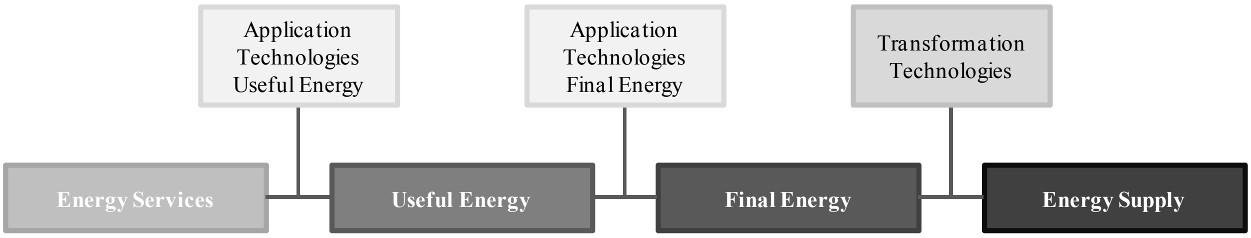
- buildings,
- mobility, and
- manufacturing.

For these sectors relevant energy services are defined (e.g. comfortable room temperature) that are the starting point for the analysis of the energy system. From the energy services the whole energy cascade is traced back to final energy demand and primary energy supply highlighting the role of different application and transformation technologies in generating energy services (see Figure 1).

[6] 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).

[7] Technology wedges depict reductions in final energy demand and emissions compared to a reference development.

Figure 1. Structure of the energy cascade



Source: Own illustration.

Technology wedges are defined for the different energy services which extends the notion of technological options as used in the original stabilization 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 greenhouse gas emissions just as e.g. electric vehicles. Thus, the technology portfolio deviates from the definition of technology in a narrow sense.

The concept of technology wedges is 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 stabilization wedges by Pacala and Socolow 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.
- All technology wedges are modelled in a uniform framework thus ensuring the comparability of technology wedges at all stages of the energy cascade.
- Economic impacts from the implementation of different technologies are analysed for the investment and for the operating phase.

The reduction triangle for Austria

Technology wedges focus on the respective emission reduction potential of different technologies. Modelling of technology wedges therefore requires a reference scenario for the development of emissions depending on GDP growth as a starting point. This scenario represents the upper boundary of the reduction triangle[8] from which changes in emissions related to different portfolios of technology wedges are subtracted.

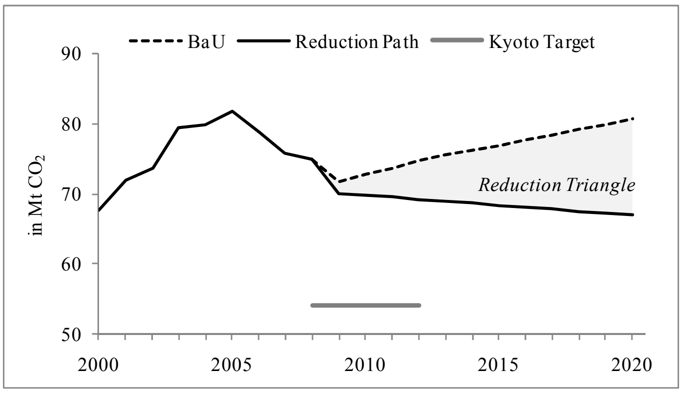
For the reference scenario energy flows are extrapolated using a structural model of the Austrian energy system. This model consists of two components: The demand component extrapolates final energy demand differentiating between economic sectors as well as between energy sources and energy use categories. The 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 are extrapolated for the reference scenario based on historical trends. CO_2 emissions are estimated to rise from 87 Mt CO_2 in 2008 to 93 Mt CO_2 in 2020 in the reference scenario.

A linear reduction path for Austrian GHG emissions is defined in line with the EU Energy and Climate Package[9]. The reference scenario and the reduction path define the emission reduction requirement until 2020, the so called "reduction triangle" as illustrated in Figure 2. The reduction requirement to comply with the EU objectives is 8 Mt CO_2 compared to 2008. The difference in CO_2 emissions between the reference scenario and the emission target in 2020 is estimated to amount to 14 Mt CO_2.

[8] The reduction trinagle illustrates the emission reduction requirement until 2020 as defined by the EU emission targets compared to a reference path.

[9] For sectors included in the EU Emission Trading Scheme (EU ETS) an EU wide emission reduction target of 21% compared to 2005 emissions applies. For the Austrian non-ETS an emission reduction of 16% is required which is equal to reduction in CO_2 emissions by 15 Mt compared to 2005.

Figure 2. Reduction triangle for Austria



Source: Statistics Austria (2009a, b), UNFCCC (2010), European Commission (2008a, b); 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.

Methodological approach for implementing technology wedges

Technology wedges in the areas buildings, mobility and manufacturing constitute different potentials and follow specific assumptions. 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 required.

Five central variables are used for describing changes in final energy demand and in emissions for each technology wedge:

- S for energy service,
- U for useful energy,
- u for useful energy intensity (amount of useful energy 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.

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

(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) multiplied by useful energy intensity (u) and final energy intensity (f).

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.

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 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 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):

(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 $\Delta f_{w,t}$.

The results can then be converted 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.

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

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.

The technology wedges approach presented in this paper extends the original method by Pacala and Socolow also with respect to economic analysis. For the period until 2020 annual investment requirements are estimated for each technology wedge. In order to assess the domestic economic implications of the implementation of the technology wedges, investment costs are split up into sectoral investment and used as the starting point for the static input output analysis calculating the direct and indirect effects of the investments. The economic analysis of the investment phase is complemented by an assessment of operating costs.

A catalogue of technology wedges for Austria

According to the concept of energy services and the common modelling approach described above technology wedges for the areas mobility, buildings, manufacturing and supply of electricity and heat are developed. Twenty-five technology wedges are analysed in detail. Technology wedges can be grouped into "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 such reductions in energy consuming sectors can originate either by a reduction of (redundant) energy services or by a decline in useful energy intensity or final energy intensity. 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 consist of a combination of both, for example if coal based electricity generation is substituted by biomass based cogeneration.

With respect to the catalogue of technology wedges it has again 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 of technology wedges is illustrated in Figure 3. The systemic approach for instance is emphasised by Technology Wedge E-4 in the sector electricity and heat supply which is the result of lower energy demand in the sectors mobility, buildings and manufacturing.

Figure 3. Catalogue of technology wedges

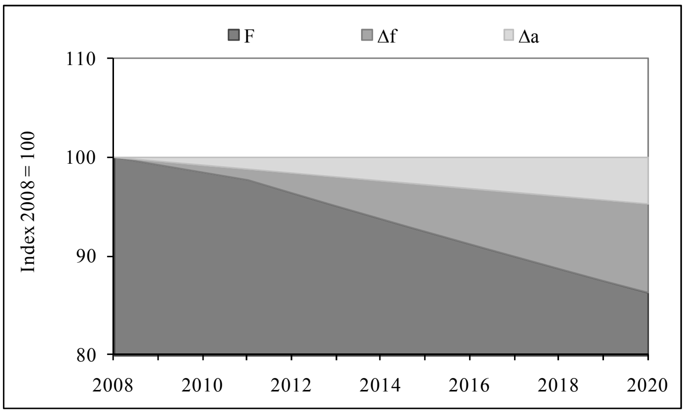
Mobility		Buildings		Manufacturing		Energy supply	
M1	Efficient land use	B1	Thermal refurbishment	P1	Energy demand industrial buildings	E1	Wind power
M2	Public transport	B2	Passive House Standard	P2	Process-intensification	E2	Hydro plants
M3	Non-motorised transport	B3a	New heating systems	P3	Energy efficient engines	E3	Biomass 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.

The common modelling approach for technology wedges is illustrated on basis of the technology wedge "replacement of heating systems". This technology wedge considers an accelerated replacement of heating systems in residential buildings of the construction period 1900 -1990. Most of these heating systems are rather old and inefficient and thus their replacement by user-optimised systems offers substantial potential for energy savings. This is increasingly acknowledged in the household sector. Starting from the current stock of about 2.7 million heating systems in the residential area the technology wedge assumes that the replacement rate rises from 2% p.a. in 2008 to 4% in 2020. It is assumed that the energy intensity of heating systems in single- and multi-family houses can on average be reduced by 10% through new technologies and optimised regulation and control. Furthermore, a continuous switch from fossil fuel-based systems to renewables occurs.

For the technology wedge "heating systems" the surface area which is heated by different heating systems and energy sources is defined as the energy service (S). The energy service decreases by about 5% up to 2020 reflecting the demolition rate of the building stock considered for replacement of heating systems. Useful energy intensity remains at a constant level, whereas final energy intensity decreases reflecting the improvement of the efficiency of the heating systems by about 10% in total (see Figure 4).

Figure 4. Effects of the technology wedge "heating systems" on useful energy and final energy



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

Changes in final energy demand and CO_2 emissions are reported in Table 1. The demand is reduced by about 14% compared to 2008, and by about 16 PJ compared to the reference scenario (164 PJ in the technology wedge scenario compared to 180 PJ in the reference scenario). These savings in final energy demand translate into a reduction of CO_2 emission reductions by about 2.1 Mt in 2020 compared to the reference scenario (4.07 Mt CO_2 emission in the technology wedge scenario compared to ca. 6.17 Mt in the reference scenario).

Table 1. Effects of the technology wedge "heating systems" on final energy consumption and CO_2 emissions

Energy source	Final energy consumption in PJ		Energy Savings in PJ	CO_2 emissions in Mt		CO_2 reduction in Mt
	2008	2020	2020	2008	2020	2020
Coal	3.26	1.45	-1.86	0.32	0.14	-0.18
Oil	54.81	33.13	-17.65	4.28	2.58	-1.38
Gas	37.76	24.45	-9.91	2.08	1.34	-0.55
Renewables	63.36	72.64	10.94	0.00	0.00	
Electricity	7.69	2.66	-4.64	0.00	0.00	
Heat	22.62	29.29	6.72	0.00	0.00	
Total	**189.50**	**163.62**	**-16.40**	**6.67**	**4.07**	**-2.10**

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

In the following, the effects of technology wedges on emissions are described in detail for the sectors mobility, buildings, manufacturing and electricity and heat supply.

Technology wedges for mobility

In the area mobility the energy service is the access to persons, goods and services needed for connecting all important functions and amenities of daily life. To simplify measurability, the energy service is, however, approximated by the variables vehicle kilometres, passenger kilometres and tonne kilometres. Vehicle kilometres or passenger kilometres, however, may be reduced or shifted 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 for the calculation of emission reduction potentials is the recently observed transport performance in passenger transport and freight transport for the different individual passenger transport modes (motorised and non-motorised), public transport and freight transport (rail and road) (Kaefer et al., 2009). Technology wedges either refer to the total transport sector or only to segments of it. For example alternative fuels concern both the passenger and freight transport sector, while the enhancement of public transport is only relevant for passenger transport.

The technology wedges aim at three major effects. First, transport performance (passenger kilometres or tonne kilometres) 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, energy efficiency is increased because of improved motor technology and/or decreased mass of vehicles.

Eight technology wedges are developed for the transport sector, calculating the emission reduction potential and the associated investment requirement. Table 2 summarises the emission reduction potentials of the technology wedges for mobility and their possible combination. In addition, for the combination of technology wedges the investment requirement for each wedge (total and compared to a reference technology) in 2020 and on average over the period 2009 to 2020 is given.

Table 2. Emission reductions and investment costs for the technology wedges for mobility

		CO_2 emission reduction			**Investment Costs in million € for combination**			
		Total	Combination		Average 2009/2020		2020	
		in Mt	in %	in Mt	Total	Additional	Total	Additional
M-1	Promotion of efficient transport saving land use	0.40	100	0.40	48	48	48	48
M-2	Improvement of public transport	0.46	76	0.35	835	835	835	835
M-3	Extension of non-motorised	0.42	83	0.35	45	45	45	45
M-4	Alternative propulsion technologies	0.15	100	0.15	453	191	1,430	583
M-5	Freight transport	0.40	100	0.40	33	33	33	33
M-6	Efficiency increase by lightweight construction of vehicles	0.50	88	0.44	2,645	0	4,829	0
M-7	Increase of biofuel additions	0.60	85	0.51	n.a.	n.a.	n.a.	n.a.
M-8	Relocation of fuel consumption	3.97	100	3.97	n.a.	n.a.	n.a.	n.a.

Source: Köppl et al. (2010); own calculations.

Technology wedges for 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 taking trends in energy demand for buildings into account. 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 the surface area is used (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.

Table 3 summarises the emission reduction potentials of each technology wedge for the building sector as well as their possible combination. In addition, the investment costs associated with each of the technology wedges in the feasible combination (total and compared to a reference technology) in 2020 and on average over the period 2009 to 2020 are reported.

Table 3. Emission reductions and investment costs for the technology wedges for buildings

		CO_2 emission reduction			Investment Costs in million € for combination			
		Total	Combination		Average 2009/2020		2020	
		in Mt	in %	in Mt	Total	Additional	Total	Additional
B-1	Thermal refurbishment of existing buildings	1.18	100	1.18	4,640	3,249	6,034	4,826
B-2	Construction of new builidings according to Passive House Standard	0.28	100	0.28	3,917	621	6,924	1,086
B-3a	Replacement of heating systems by more efficient systems based on	2.10	70	1.47	595	145	638	189
B-3b	Intensified use of solar heat for space heating and hot water preparation	0.35	70	0.25	834	668	734	541
B-4	Increased power production of builidings for own consumption	0.00	100	0.00	64	44	95	70
B-5	Energy optimised appliances, lighting and equipment	0.00	100	0.00	1,439	n.a.	1,519	n.a.

Source: Köppl et al. (2010); own calculations.

Technology wedges for manufacturing

Despite an improvement in energy efficiency in the last decades energy demand from manufacturing in absolute terms has been constantly rising. In 2008 the share of the industry sector in total Austrian final energy consumption was 29%. Industry thus is the third area for which technology wedges are developed. 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.
- Mechanical energy services cover the provision of mechanical and kinetic energy that are provided by engines which transform thermal, chemical or electrical energy into mechanical or kinetic energy. Generally industry sectors have a considerable and increasing share of this service because of rising automation of technical processes.
- Specific electric 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 technology wedges are developed for the Austrian industry sector. Table 4 summarises the emission reduction potentials of the technology wedges for manufacturing and their possible combination. Furthermore, the investment costs for the feasible wedge combination (total and compared to a reference technology) in 2020 and on average over the period 2009 to 2012 are depicted.

Table 4. Emission reductions and investment costs for the technology wedges for manufacturing

		CO_2 emission reduction			Investment Costs in million € for combination			
		Total	Combination		Average 2009/2020		2020	
		in Mt	in %	in Mt	Total	Additional	Total	Additional
P-1	Energy demand for industrial buildings	0.25	100	0.25	131	131	143	143
P-2	Process intensification and process integration	1.49	100	1.49	185	185	202	202
P-3	Energy efficient engines	0.06	88	0.05	51	51	56	56
P-4	Combined heat and power	-0.21	94	-0.20	26	25	28	28
P-5	Substitution of fossil energy sources with high emission-coefficients	0.84	67	0.56	4	-1	4	-1
P-6	Biomass for process heat	0.61	85	0.52	27	25	30	27
P-7	Solar thermal energy for process-heat and space heating	0.25	100	0.25	103	102	112	111

Source: Köppl et al. (2010); own calculations.

Technology wedges for 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. Technology wedges are hence developed for reducing emissions from fossil electricity and heat supply.

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, e.g. by the use 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 four technology wedges are developed. On the one hand the options include a shift to renewable electricity generation and co-generation, on the other hand the energy saving potential of the technology wedges for the sectors mobility, buildings and manufacturing are taken into account in one technology wedge. This technology wedge calculates the emission reduction potential in the energy sector determined by efficiency gains on the demand side subsequently leading to reduced fossil electricity and heat generation.

Table 5 summarises the emission reduction potentials of technology wedges for the sector electricity and heat supply as well as their possible combination. Investment costs associated with each of the technology wedges in the combination (total and compared to a reference technology) are reported for 2020 and for the whole implementation period.

Table 5. Emission reductions and investment costs for the technology wedges for electricity and heat supply

		CO_2 emission reduction			Investment Costs in million € for combination			
		Total	Combination		Average 2009/2020		2020	
		in Mt	in %	in Mt	Total	Additional	Total	Additional
E-1	Wind power	1.00	100	1.00	80	80	80	80
E-2	Hydro power	1.00	100	1.00	87	87	75	75
E-3	Biomass and biogas CHPs	1.00	100	1.00	62	62	66	66
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.

Source: Köppl et al. (2010); own calculations.

Technology wedge portfolios for the reduction triangle

Technology wedges filling the reduction triangle can be grouped into “efficiency wedges” and “fuel shift wedges” (see above). Filling the reduction triangle can either have a stronger focus on "efficiency wedges" or on "fuel shift wedges". In this paper two different technology wedge portfolios are presented, 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.

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 as well as their effects on the electricity and heat supply are analysed. 18 technology wedges are considered to fill the reduction triangle and achieve an emission reduction of 14 Mt CO_2 in 2020 (see Table 6)[10].

[10] The emission reduction potential of the different technology wedges is given in Tables 2 to 5.

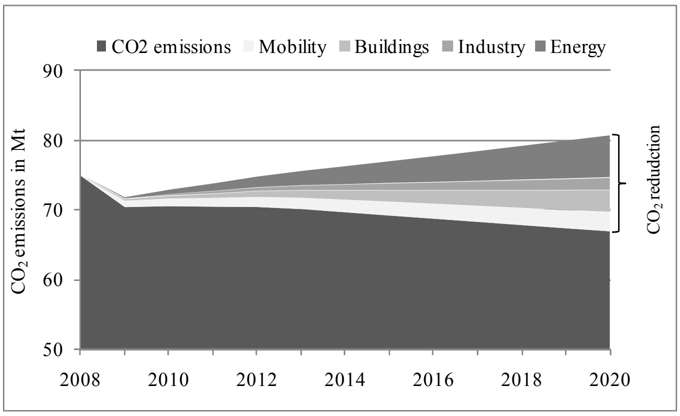
Table 6. Technology wedge combination for the energy efficiency portfolio

	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

Source: Own illustration.

In Figure 5 the emission reductions are aggregated by sector and contrasted with the emissions in the reference scenario. Emission reductions from the mobility sector are 2.8 Mt CO_2 in 2020. The technology wedges in the building sector achieve reductions of 3.2 Mt CO_2 in 2020 compared to the reference scenario. Emission reductions in the manufacturing sector amount to 1.8 Mt in 2020 in this technology wedge portfolio. The largest emission reduction – 6 Mt 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 [11].

Figure 5. Technology wedge portfolio focusing on energy efficiency compared to reference scenario



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

A technology wedge portfolio focusing on low carbon fuels

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. For this portfolio primarily technology wedges addressing a fuel shift in energy supply or in energy demand are considered. In order to fill the reduction triangle, however,

[11] The shares of the building and the manufacturing sector in this reduction are 39% and 61% respectively.

some technology wedges that focus exclusively on improvements in energy efficiency need to be included. The 20 technology wedges considered to fill the reduction triangle are listed in Table 7[12].

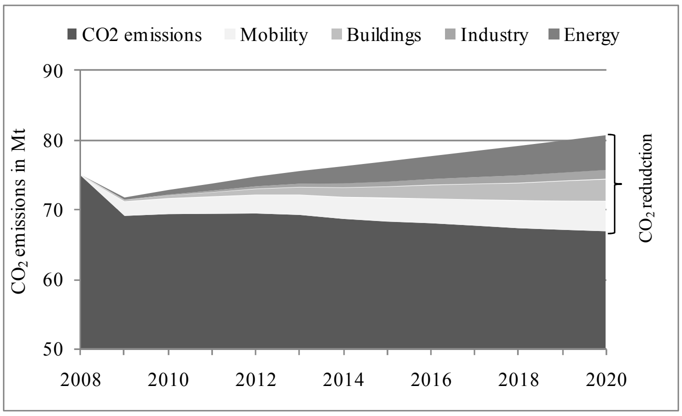
Table 7. Technology wedge combination for the low carbon portfolio

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-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 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
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-river 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

Source: Own illustration.

The contribution of each sector to the total emission reduction of 14 Mt CO_2 in 2020 is illustrated in Figure 6. Technology wedges for mobility achieve an emission reduction of 4.3 Mt CO_2 in 2020 compared to the reference scenario. Emission reductions in the building sector amount to 3.1 Mt CO_2 in the low carbon portfolio. Manufacturing and supply of electricity and heat contribute reductions in CO_2 emissions of 1.3 Mt and 5 Mt respectively[13].

Figure 6. Technology wedge portfolio focusing on low carbon fuels compared to reference scenario



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

[12] The emission reduction potential of the different wedges is given in Tables 2 to 5. For the portfolio 43% of the emission reduction of Technology Wedge M-8 is considered. Technology Wedge E-1 (‘wind power’) achieving a reduction of 1 Mt CO_2 is included twice thus contributing a CO_2 reduction of 2 Mt.

[13] The building sector, however, accounts for 19% of the emission reduction in the energy sector through reductions in electricity and heat demand.

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). Furthermore, an assessment of operating costs effects of the technology wedges is provided. In the following, the results for the technology wedge portfolios are presented.

Input-output effects

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. Additional investment costs apply to cost differences compared to a respective reference technology. In order to assess the economic implications of the implementation of technology wedges, investment costs are split up into sectoral investment shares. The diffusion of technologies over time 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 the transformation of the energy system 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 two portfolios are listed in Table 6 and Table 7, the additional investment costs required for each wedge on average over the twelve-year period from 2009 to 2020 as well as in 2020 are given in Tables 2 to 5. For the energy efficiency portfolio, additional investment costs amount on average to 6.2 bn € and to 8.7 bn € in 2020. The respective investment requirement for the low carbon portfolio is 6.3 bn €and 8.6 bn €. In both portfolios, the highest share in additional investment costs accrues to the building sector.

The economic effects of the technology wedge portfolio focusing on energy efficiency can be summarised as follows: 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 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 in 2020 compared to the twelve-year average mainly result from the higher additional investment costs in this year. Due to its 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.

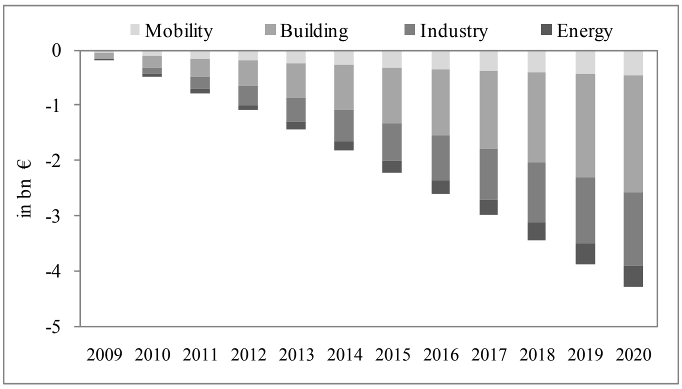
As the level and structure of investment for the two technology wedge portfolios resemble, output and employment effects of the low carbon portfolio are similar to those of the energy efficiency portfolio.

Effects on operating costs

The implementation of the technology wedge portfolios 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 7 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[14]. In line with the large contribution of the building sector to investments and emission reductions in this portfolio operating cost savings are highest in this sector reflecting the significant energy savings. Figure 7 clearly illustrates the cumulative character of the operating cost effect. In 2020 operating cost savings amount to 4.3 billion €.

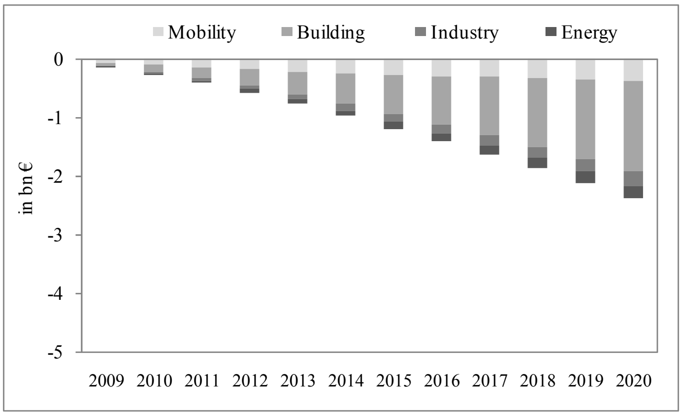
Figure 7. Operating cost savings of the energy efficiency portfolio



Source: Köppl et al. (2010); own illustration.

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 (see above).

Figure 8. Operating cost savings of the low carbon portfolio



Source: Köppl et al. (2010); own illustration.

Conclusions

The objective of limiting anthropogenic climate change requires a fundamental restructuring of energy systems, i.e. current patterns of energy use and generation. The starting point for the necessary changes should be to shift the focus from energy flows – as in conventional energy statistics and models – to energy services. In order to provide the desired energy services in an efficient and sustainable way the guidelines "low energy – low carbon – low distance" should be used. This refers to an increase in energy efficiency, the reduction of fossil fuels as well as the reduction of redundant mobility.

In the research presented in this paper, an extended concept of technology wedges is used for Austria to illustrate options for technological and behavioural changes that follow the principle described above. The focus is on the

[14] 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.

one hand put on relevant areas of final energy demand (buildings, mobility, manufacturing) and on the other hand on electricity and heat generation.

The assumed reference path of energy demand and emissions until 2020 and the assessment of technology options suggest that there is a large requirement for emission reductions in order to reach the EU climate policy objectives. This implies that not only the most cost efficient technologies are implemented but suggests that all available technological options have to be exploited to achieve a significant decarbonisation of the energy system. It has to be emphasized, however, that the reduction potential can be considerably increased if changes in lifestyles and preferences occur as well.

References

European Commission, (2008a), Commission staff working document; Accompanying document to the proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the EU greenhouse gas emission allowance trading system, Brussels.

European Commission, (2008b), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Region, '20 20 by 2020. Europe's climate change opportunity', COM 2008/30 final.

Kaefer, A., Steininger, K, (2008), Raumordnung und Klimaschutz, im Auftrag der Salzburger Landesregierung, Salzburg.

Köppl, A., Kettner, C., Kletzan-Slamanig, D., Schnitzer, H., Titz, M., Damm, A., Steininger, K., Wolkinger, B., Artner, H., Karner, A., Lang, R., Wallner, G., Schleicher, S., (2010), EnergyTransition 2012\2020\2050 Strategies for the Transition to Low Energy and Low Emission Structures (Final Report). Vienna.

Nakicenovic, N. (ed.), (2005), Intergovernmental Panel on Climate Change Special Report on Emission Scenarios, Cambridge.

Öko-Institut and Prognos, (2010), Modell Deutschland – Klimaschutz bis 2050: Vom Ziel her denken. Endbericht. Berlin.

Pacala, S., Socolow, R., (2004), Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science, 305, 968-972.

Socolow, R., Hotinski,R., Greenblatt, J.B., Pacala, S., (2004), SOLVING THE CLIMATE PROBLEM. Technologies Available to Curb CO_2 Emissions, Environment, Vol. 46, p. 8-19.

Statistics Austria, (2009a), Energy balances 1970-2008 – Detailed information, Vienna.

Statistics Austria, (2009b), Useful energy analysis (Special statistical evaluation). Vienna.

Stern, N., Peters, S., Bakhshi, V., Bowen, A., Cameron, C., Catovsky, S., Crane, D., Cruickshank, S., Dietz, S., Edmonson, N., Garbett, S.-L., Hamid, L., Hoffman, G., Ingram, D., Jones, B., Patmore, N., Radcliffe, H., Sathiyarajah, R., Stock, M., Taylor, C., Vernon, T., Wanjie, H., Zenghelis, D., (2006), Stern Review: The Economics of Climate Change, HM Treasury, London.

UNFCCC, (2010), National inventory submissions 2010. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php

Acknowledgements

This paper is based on the results of the project EnergyTransition (Köppl et al., 2010). The project was funded by the Austrian "Klima- und Energiefonds" and was carried out within the research programme "Energie der Zukunft".