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AN INDICATOR FOR SUSTAINABILITY

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‘ECOLOGICAL VALUE ADDED’ IN AN INTEGRATED ECOSYSTEM-ECONOMY MODEL – AN INDICATOR FOR SUSTAINABILITY

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Abstract: This paper sets up an input-output system of the relevant ecosystem flows that determine the carbon cycle in the global ecosystem. Introducing energy as the value added component in the ecosystem, the flows can be expressed in ‘energy values’. Linking the ecosystem input-output model with the economy input-output model allows to calculate the ecosystem costs of excessive fossil energy use in terms of additional carbon sinks for emission absorption, that need solar energy input, i.e. ‘ecological value added’. The model lined out in this paper enables to calculate costs and prices of the ecosystem due to anthropogenic fossil energy use. It might be useful (i) to derive sustainability indicators and (ii) as a framework for environment-economy links in E3 models.

Key words: climate change, environmental accounting, input-output

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Introduction

Environmental accounting has become an important instrument of official statistics during the last decade as a foundation of empirical analysis and of economic and environmental policy. Statistical and research institutions of many countries have during the last decade begun to collect physical data about emissions and use of the environment by economic activity according to the UN system of 'Integrated Environmental and Economic Accounting (SEEA)' as well the EUROSTAT system 'SERIEE'. The main line of development in these concepts is the construction and integration of 'satellite' accounts into SNA, so that hybrid measures of monetary and physical units arise. A full integration of economic and environmental accounting is still missing, because the 'valuation problem' still remains unresolved in environmental accounting. There are different approaches which attempt to set up a base for valuation of environmental degradation due to economic activity such as the abatement costs approach or contingent valuation. The most important drawback of these concepts is that the valuation base remains fully arbitrary and results from different measurement methods differ considerably.

At the same time almost a decade ago the concept of 'sustainability' or 'sustainable development' was introduced by the UN Report of the World Commission for Economic Development (1987), which became known later as the 'Brundtland-Report'. Since then the research in ecological economics has been engaged in finding indicators for (ecological) sustainability, i.e. if a certain development path is sustainable from an ecological perspective for future generations. Among the literature on these 'sustainability indicators' one finds a strong link to physical accounting (for a literature overview see: van den Bergh (1996)). The research on sustainability also has begun to take into account the relevant ecosystem features to get a clear picture of the nature and amount of human perturbation by economic activity. A comprehensive approach of 'ecosystem services' has been laid down by Norberg (1999). He differentiates between various service functions of ecosystems including resource use, value of utility, carrying capacity for absorption of emissions and stability due to biodiversity. The carrying capacity concept has been the main link for the ‘ecological footprint indicator’ (EF) proposed by Wackernagel, Rees (1996). This approach tries to quantify the ecosystem resources in land and water, that would be necessary to supply all resources the population consumes and to absorb all the wastes that are produced. The emphasis of the EF concept is on the indicator aspect, as it actually attempts to quantify the ‘overshooting’ of human activity beyond the carrying capacity of ecosystems. On the other hand it has been heavily questioned, if this promise of the EF concept is actually fulfilled in the practical use and if the EF can therefore be seen as a relevant indicator for policy guidance at the national level. These points have been discussed very controversially among ecological economists (Ayres (2000), Constanza (2000), van den Bergh, Verbruggen (1999), etc.). One important point of the critique applies to the method converting the ‘overuse’ of the ecosystem by fossil energy use into additional forest land (i.e. carbon sinks), that would have been necessary to absorb the carbon emissions from fossil energy use. Another point of the critique concerns the spatial dimension of the EF if applied to countries or small populations (van den Bergh, Verbruggen (1999)). As has also been pointed out, aggregating all environmental problems into the land use dimension using conversion factors ignores the complexity of ecosystems and the interdependencies between different environmental impacts. On the other hand there are also extensions of the EF concept, demonstrating the analytical potential for applications, as for example the input-output analysis linked to the EF in Bicknell, et al. (1998).

Another line of research in ecological economics, which can be described as the ‘biophysical’ approach (van den Bergh (1996)) has developed a method to evaluate ecosystem flows based on energy as the relevant ‘currency’. This approach stays within ecosystem research and uses input-output (i-o) analysis to calculate direct and cumulative energy content of ecosystem flows (Hannon, Costanza, Herendeen (1986), Costanza (1991), Hannon (1991, 1995)). These studies have introduced energy i-o analysis in ecosystems research to develop indicators for total embodied energy as well as values in terms of ‘energy values’ or ‘ecological interdependence factors’ as in Costanza (1991), derived from the commodity balances of make/use system (processes*commodities) with joint production. Part of the emphasis of this research line is on technology assumptions of a processes*commodities ecosystem i-o model and on the treatment of joint production. The aim is to derive values in an ecosystem model as explicitly suggested in Costanza (1991) and Hannon (1991). Also linking of the ecosystem to economic activity is considered in this line of research (Costanza (1991)).

This paper tries a synthesis of the different approaches in order to propose a valuation concept for ‘overuse’ of the ecosystem by fossil energy use. The scope of the paper is therefore limited as far as environmental problems dealt with are concerned. On the other hand it shall be argued that the approach proposed can be enlarged in order to incorporate different environmental repercussions of economic activity. Starting point is an i-o model of the carbon and energy flows in an example ‘global ecosystem’ using the most recent data for the global carbon cycle from Houghton, et al. (2001). Applying the ideas of Hannon, Costanza, Herendeen (1986), Costanza (1991) and Hannon (1991, 1995), the flows can be converted into energy values using only solar energy as the value added component.

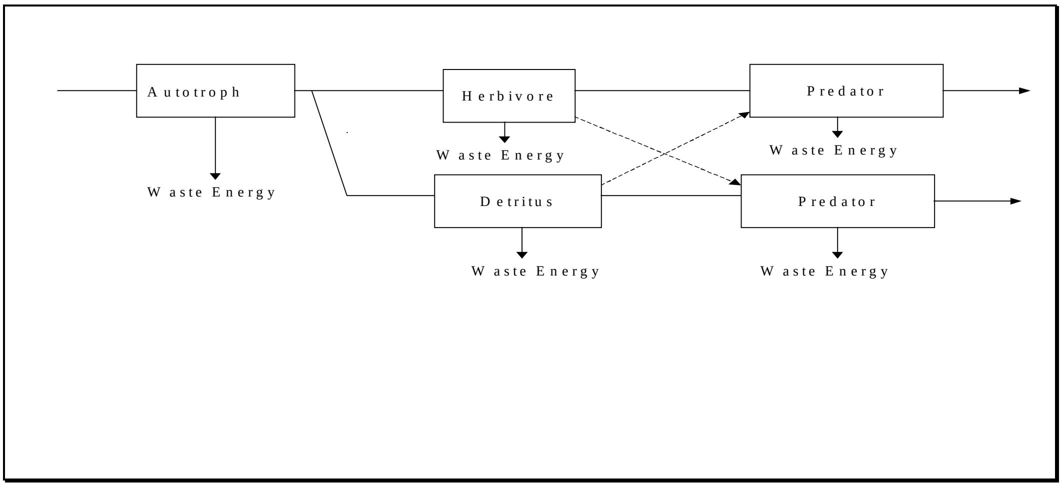
The physical i-o table of the carbon cycle is then enlarged by linking it to a two activity (example) economy, where the link area is what is usually treated with in satellite accounts of environmental accounting, i.e. carbon emissions of activities. This integrated ecosystem-economy i-o table is in a first step constructed without additional emission absorption by the ecosystem, so that the anthropogenic carbon emission leads to an increase in atmospheric concentration of carbon. Taking up the original idea of the EF in a further step an integrated ecosystem-economy i-o table is set up, where the *necessary* emission absorption activity in order to *achieve a certain political target of net carbon release to the atmosphere* is introduced. This emission absorption activity is represented as an additional activity of the input-output model like the abatement activity in Leontief's pollution model (Leontief (1970)). The assumption of using additional forest land for carbon absorption is not seen as a limitation, but as the only way, by which the ecosystem itself can handle carbon mitigation from the atmosphere. Therefore the i-o quantity and price model can be presented with a solution for physical quantities in different units and prices in ‘energy values’. That allows to calculate the ‘ecological value added’ of a certain amount of emission absorption and to derive an i-o table in energy values as well as monetary units. One possible indicator for sustainability might then be the relationship of ‘ecological value added’ in energy values to total GDP in energy values or in monetary terms.

The final section of the paper describes the results of a simulation experiment concerning technical change, where the implicit assumption is that energy efficiency increases due to any carbon mitigation policy (emission trading, regulation, etc.) and the economic final demand, i.e. the GDP, remains the same.

1. The carbon cycle in an ecosystem i-o model

Starting point for the input-output model outlined here are the basic features of the relevant ecosystem activities, that contribute to the global carbon cycle. As far as the data and the schematic description of the carbon cycle are concerned, the empirical example chosen here is based on the Third Assessment Report, Part 1 (Houghton, et al. (2001)). The theoretical base to describe the ecosystem as an input-output system has been taken mainly from Odum (1983). The main concepts of ecology to describe the bio-geochemical cycle of carbon and the related energy flows is an energy flow diagram along a line of trophical levels. First of all the differentiation between autotroph organisms, i.e. plants, and heterotroph organisms (herbivores, predators, the human being, etc.) is introduced, where only autotroph organisms are able to use the free solar energy to synthesize biomass from carbon and water in the atmosphere. In this sense autotroph organisms are the primary producers in an ecosystem. Another ecosystem compartment is detritus, where biomass is converted into CO_2 via fermentation by bacteria, with an intermediate level of methan production. The trophical chains of autotroph, heterotroph and detritus compartments are very complex and contain different chemical materials (nitrogen, phosphor, etc.) as Odum (1983) has shown for aquatic ecosystems. The primary energy flow in the system stems from solar energy, which is absorbed by plants and then transported through the system as in *Graph 1*. Energy and carbon are directly related, as energy is stored in carbon by photosynthesis and is used in respiration in the form of carbon. That might be seen as a special feature regarding the relationship of energy and mass flows in the case of carbon as compared to, for example nitrogen, water, phosphor, etc. . The general aspect of this relationship is that energy flows are needed to move any bio-geochemical cycle also in the case of other materials. In the case of carbon waste, energy is produced by respiration at any trophical level and carbon is used by the own or another trophical level. Ecosystems differ considerably as far as the distribution of the flows in *Graph 1* is concerned. At the first trophical level after the autotroph organisms the distribution between the use of the produced biomass by herbivore organisms and by detritus is organized. In the case of tropical forests almost 90 percent of the biomass flows goes directly to detritus and is not used by herbivores, for grassland this proportion amounts to 50 percent. From herbivore and from detritus biomass further flows to predators and to other trophical levels (as the human being), certain flows are also possible in some ecosystems between the detritus trophical chain and the herbivore trophical chain (the dashed lines). If we included other material flows than carbon in the picture like nutrients as in Hannon (1991) and Costanza (1991), flows between all trophical levels would occur. This enlargement of the model should in general be possible and give the base for a more comprehensive ecosystem input-output model. Nevertheless this paper limits itself to the issue of carbon flows and climate change as the environmental problem.

Graph 1: Energy flow in an ecosystem



Graph 1 shows that energy is a continuos flow through the ecosystem driving the flows of carbon, which are circular. Carbon flows are represented by photosynthesis and respiration, where the main chemical identities are:

$$\text{(1)} \quad CO_2 + 2\,H_2O \xrightarrow{\text{Solar energy}} (CH_2O) + H_2O + O_2$$

$$\text{(2)} \quad CH_2O + H_2O + O_2 = CO_2 + 2\,H_2O$$

These equations describe in a stylized form the circular flows of carbon in an ecosystem, which constitute the bio-geochemical cycle of carbon.

Equation (1) describes the process of *gross production* of the ecosystem by plants, by which solar energy is absorbed. The *solar constant* is assumed with 50 TJ per hectare land per year, which represents the amount actually available to be assimilated by plants. The effectively used amount of solar energy for biomass gross production is about 1 percent of that. Part of the *gross production* is already used by plant respiration and fires of forests, so that about half of the *gross production* is only converted into *net production*. This *net production* is available for the other trophical levels of the ecosystem and is used up in total by heterotroph respiration or detritus fermentation (equation (2)).

In a more detailed perspective the chemical processes involved would look much more complicated. On the other hand also the ocean and chemical processes are engaged in the global carbon cycle, where dissolution of carbon and transformation to $CaCO_3$ play an important role. All these detailed processes shall not be described in this paper. The purpose of this research is just to outline an ecosystem model, which in a stylized manner takes into account the most important transactions in a physical sense, which contribute to the global carbon cycle. The main scientific results from ecology applied to this model are:

- energy flows drive the bio-geochemical cycles on earth and are in the form of solar energy the main primary input

- materials circulate in the ecosystem in bio-geochemical cycles, where in the case of carbon the compartment of autotroph organisms can be seen as the ‘primary producer’, acting as the main sink of anthropogenic carbon emissions.

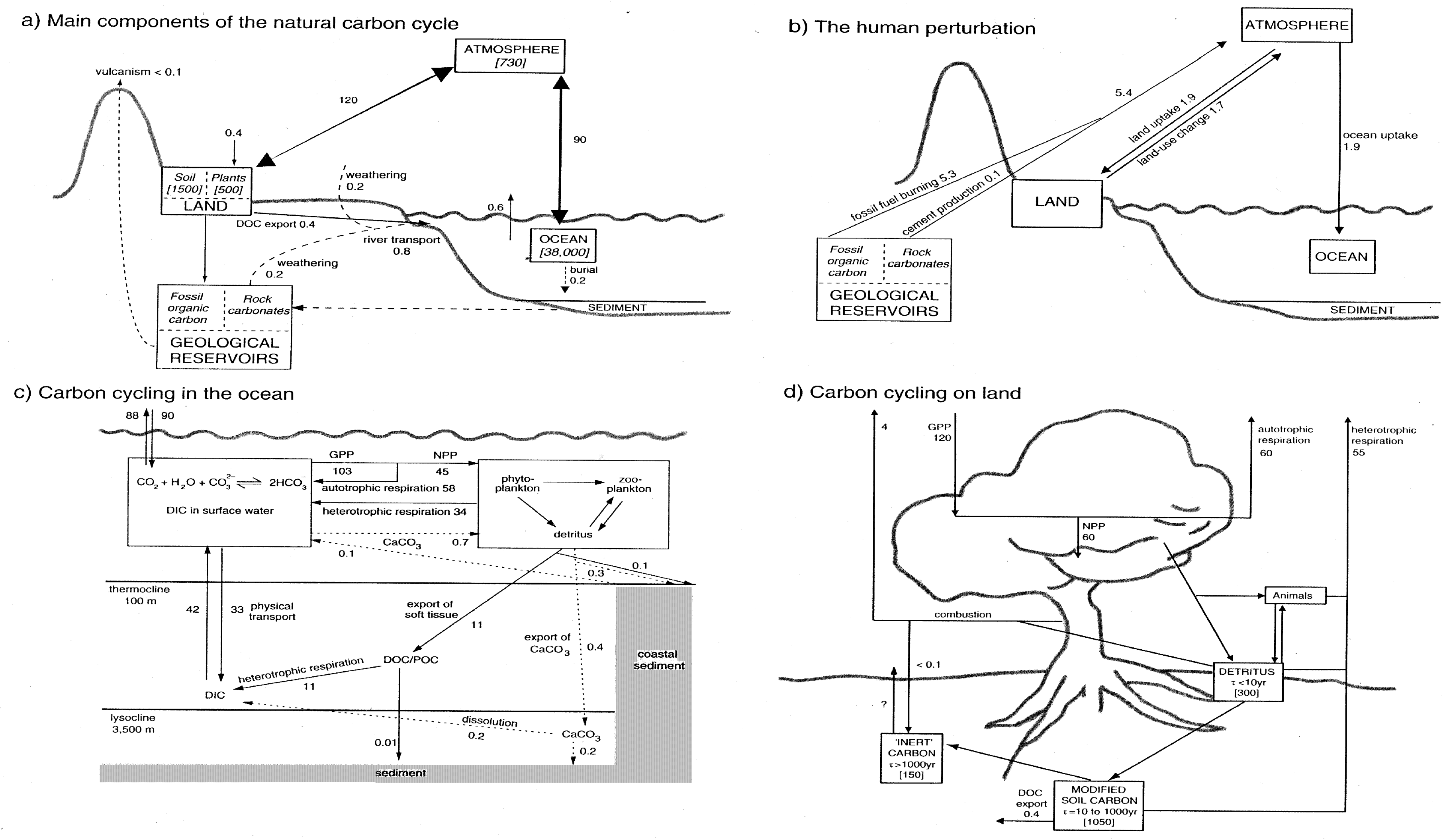
The main data for the empirical example used here are taken from Houghton, et al. (2001) and are combined with assumptions about the biomass flows between autotroph, heterotroph and detritus. *Graph 2* describes the most important gross flows in the global carbon cycle in PgC (petagramm Carbon), which entered in the physical input-output table (*Table 1*).

Table1: Physical Input-Output Table of the Ecosystem: Carbon Flows

Additional data from Houghton, et al. (2001) have been used for the distribution of land area across different types of ecosystems and the corresponding carbon stock:

	Stocks, 10^9 ha	Stocks, PgC
Forests	4,16	1.240
Grassland	9,43	811
Croplands	1,35	169
Total	14,94	2.220

Graph 2: The Global Carbon Cycle (Houghton, et al. (2001))



The main production data in PgC for terrestrial ecosystems and the ocean derived from Houghton, et al. (2001) and used for the input-output table comprise:

	Gross Production	Respiration (incl. fires)
Forests	57,8	32,9
Grassland	51,8	25,9
Croplands	8,2	4,1
Ocean-Phytoplankton	103,0	56,6

The assumptions for the first level flows of biomass from autotroph to detritus are 50 percent for grassland and ocean phytoplankton, 90 percent for forests and 20 percent for agriculture.

Table 1 shows a system with one part of human activity in the carbon cycle by including agriculture, but without taking into account the fossil energy use of agriculture. The carbon flows associated with agriculture therefore only include the mass flows due to production and consumption of plant and animal biomass. The physical input-output table presented in *Table 1* is essentially an 'anthropocentric' table, where the last use (= final demand) of all activities is human consumption. The activities are: autotroph, heterotroph, detritus and agriculture, the two environmental media are soil/ocean and the atmosphere. As primary inputs the stocks necessary for production in carbon and in area dimensions are included and solar energy appears as the 'value added' component. As a matter of completeness the stocks of carbon in the environmental media have also been added, showing the atmospheric value of 730 PgC equivalent to a concentration of 367 ppm.

Stock accounting plays an important role in the accounting framework presented in *Table 1* and the derivation of a dynamic input-output model based on the static framework of *Table 1* and on the knowledge of the functional forms of the stock-flow relationships could be an interesting application of this model. The addition to stocks is treated as a final demand component, which for this input-output table without fossil energy use shows a carbon uptake of soil and ocean of about 5,1 PgC. This carbon uptake stems from 3,7 PgC land uptake, which is just the net biomass accumulated and 1,4 PgC which enters as inert and dissolved carbon in the ocean. That means that for the numbers used here in a carbon cycle without human perturbation the atmosphere would in this period 'loose' 5,1 PgC of carbon concentration, which would show up as inert carbon in the media soil/ocean. This could be described as an 'oversustainable' situation, as human activity could use up these 5 PgC for fossil energy use. To a certain extent the 5,1 PgC represent the 'resource service' of the ecosystem. The uptake of atmosphere and the inert carbon stock increase balance out across the environmental media, so that the vector of carbon stock change only contains zero elements across the four sectors considered.

The transactions between the two environmental media and the activities are based on the carbon flow data from *Graph 1*. One could think of a more detailed and elaborated model regarding the ocean, where ocean phytoplankton could be treated as an activity. That was dismissed here for the case of simplicity. Carbon emissions from final consumption are implemented here as a negative sink. The atmospheric balance is given by sink uptake through autotroph and agriculture and emissions from all sectors and 0,4 PgC flow from soil/ocean to the atmosphere, i.e. a flow between environmental media.

Table 2: Technical Coefficients of the Ecosystem Model

Table 3: Leontief-Inverse of the Ecosystem Model

The matrix of technical coefficients as well as the Leontief inverse can be calculated from the i-o table comprising the four sectors. For the quantity model we can link the atmosphere flows of sinks and emissions by input and emission coefficients to final demand:

(3) $\mathbf{C_S} = \mathbf{c_S} [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{F} + \mathbf{c_F} \mathbf{F}$; $\mathbf{C_E} = i' \mathbf{\hat{C}_E} [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{F}$

with $\mathbf{C_S}$ as a row vector of carbon sinks and $\mathbf{c_S}$ as a row vector of carbon sink coefficients per unit of output, $\mathbf{C_E}$ as a row vector of carbon emissions and $\mathbf{\hat{C}_E}$ as a diagonal matrix of carbon emission coefficients per unit of output. The unit row vector **i´** is used for summation and **F** stands for the column vector of final demand. Equation (3) also takes into account, that part of the emission stems directly from final demand activities with $\mathbf{c_F}$ as a row vector of final demand emission coefficients (negative sink coefficients) assuming that emissions can be attributed to single commodity demand within final demand. As the carbon stock vector is zero and atmosphere loss of carbon equals soil/ocean uptake, emissions and sinks are also balancing out, so that $\mathbf{C_E} = \mathbf{C_S}$.

It must be noted that final demand in this setting also includes carbon stock and the input into the environmental media soil/ocean and atmosphere. For the case of atmosphere these are equal to the carbon emission vector $\mathbf{C_E}$. That yields an equation system with:

(4) $\mathbf{C_S} = \mathbf{c_S} [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{F} + \mathbf{c_F} \mathbf{F}$

(5) $\mathbf{C_E} = i' \mathbf{\hat{C}_E} [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{F}$

(6) $\mathbf{F} = \mathbf{C_E} + \mathbf{F^*}$

with **F*** as exogenous final demand including human consumption and carbon stock change, the latter being zero among the four sectors treated. As part of the final demand therefore becomes endogenous in this model, the solution would be to extend the i-o model to include environmental media (soil/ocean, atmosphere) as is usually done in social accounting matrices (SAMs). Equally the system could be solved simultaneously for equations (4) to (6) as any macro/i-o model with part of the final demand depending on gross output.

In any case the resulting quantity i-o model can be used for traditional i-o analysis, for example the ecosystem impact of an increase in human meat consumption.

The i-o price model can be used to derive 'energy value prices' $\mathbf{p_E}$, if we take the row vector $\mathbf{v_E}$ as the value added component of the system in terms of solar energy inputs per unit of output.

(7) $$\mathbf{p_E} = \mathbf{v_E} [\mathbf{I} - \mathbf{A}]^{-1}$$

This finally allows to derive the i-o table in energy values, where all transactions along the rows have been multiplied by the corresponding energy value-price. This gives final demand in energy value-prices and compound prices for demand components in energy value added. Introducing energy as one homogenous value added component therefore suffices to derive carbon flows in value terms consistent with i-o analysis.

Table 4: Ecosystem Model (Carbon) in 'Energy Values'

2. An integrated ecosystem-economy model and the carbon cycle

The model of the last section can be extended now in order to include fossil energy use as well as land use change as the two main sources of anthropogenic perturbation of the ecosystem carbon cycle. The link for the economy and the ecosystem are the carbon emissions of human economic activity, which are usually accounted for in the satellite systems of environmental accounting. Two types of the integrated model will be presented here, the first one without additional emission absorption capacities of the ecosystem. In that case the additional anthropogenic carbon emission leads to an increase in atmospheric concentration of carbon.

The second type of integrated model includes the ecosystem capacity of forests, that *would have been necessary* to absorb anthropogenic carbon emissions. This activity is introduced as an abatement activity as in Leontief's original pollution model (Leontief (1970)). In this type of model the ‘ecological value added’ of the necessary emission absorption can be calculated and indicators for sustainability can be derived.

The physical i-o table of the ecosystem is extended in order to include two economic activities, namely agriculture and industry/services. Agriculture has already been part of the pure ecosystem model, where all physical flows have been measured in PgC. Now agriculture is treated as part of the economic system with physical flows in economic relevant units (for example bushels of wheat as in Leontief (1970)).

Table 5: Physical Input-Output Table of Integrated Economy-Ecosystem Model: Carbon Flows without Emission Absorption

The carbon flows of agriculture are still in PgC and comprise as before the carbon uptake (sink) from atmosphere due to gross production, carbon emission due to plant respiration and additionally carbon emission from fossil fuel use and from land use change. The total anthropogenic emission of carbon due to fossil fuel use (5,3 PgC) and to land use change (2 PgC) are distributed among agriculture, industry and final demand. In the case of agriculture the 4,1 PgC from respiration have been included in the emission vector as well as in anthropogenic carbon in order to guarantee consistency of the carbon flow balance. Again the carbon emissions of final demand are accounted for as negative sinks and all fossil energy emissions of industry can be found in the corresponding cell of anthropogenic carbon.

Again applying equations (4) to (6) we find out, that in this table anthropogenic additional emissions are not compensated by other carbon stock changes and therefore stay in the atmosphere as additional carbon uptake, so that $\mathbf{C_E} > \mathbf{C_S}$. The model could be formulated to have carbon stock as the balancing item, so that the atmosphere would then take up 2,3 PgC instead of loosing 5,1 PgC as in the pure ecosystem model. The difference of 7,4 PgC is exactly the sum of 2,1 PgC of land use change and 5,3 PgC of carbon emissions from fossil fuels, both accounted for in anthropogenic carbon. The uptake of 2,3 PgC in the carbon stock of 730 PgC in the atmosphere would result in this static framework in an increase of atmospheric concentration of about 1 ppm. It must be noted again, that what is proposed in this paper is only a *static accounting framework*. It could be further developed to represent a dynamic model, where all dynamic functions between different carbon stocks could be integrated. In such a setting a certain amount of carbon release to the atmosphere would not lead to an exactly one to one increase of atmospheric concentration.

The quantity model of this table gives a solution for the *hybrid* output vector, where agriculture and industry output are measured in economic relevant units and the other outputs are measured in carbon units (PgC). The model without emission absorption can also be solved for energy value prices according to equation (7) in order to arrive at prices in energy values for all activities. Also this model can be used for standard i-o analysis of the impact of changes in the final demand vector on outputs.

2.1 Quantities in an integrated model with emission absorption

The system can in a next step be further extended in order to include the emission absorption function of the ecosystem. As has been pointed out in section 1 energy and carbon flows are directly related in an ecosystem between the compartments or trophical levels and the atmosphere on the other hand. Only autotroph organisms are able to take up carbon from the atmosphere and convert it into biomass by photosynthesis. The human perturbation introduced in the last section intervenes in this cycle by burning fossil fuels and converting greenland into land, where no photosynthesis takes place. The direct ecosystem consequence of this anthropogenic impact is an increase in atmospheric carbon concentration. In terms of the ecosystem there is a disequilibrium between the capacity of photosynthesis to take up carbon from the atmosphere and anthropogenic carbon release.

The method proposed here to account for that is similar to the EF concept, namely by introducing the *theoretically necessary autotroph production capacity* to absorb these emissions. Within the boundaries of this model that might be justified as it is the only way by which the ecosystem itself can cope with emission absorption. Although Ayres (2000) has pointed out, other methods for 'natural' carbon absorption like carbon uptake in the oceans exist, but these are all essentially *anthropogenic* measures. Technologies and capital from the economic sphere have to be applied to carry out these other ‚natural‘ carbon absorption options. It must be noted again that with assuming the introduction of the *theoretically necessary autotroph production capacity* nothing is said about a sustainable scenario or target and about desirability of reforestation as carbon mitigation policy. It is simply introduced as the 'ecosystem abatement sector' for emissions. The critizism on the the aggregation bias of the EF, when applied to all environmental problems together is not valid in this singular case of carbon emissions. Partly has the EF also been criticised stressing the concept too far. The EF does not, as part of the critics point out, design an 'alternative energy use sustainability' scenario, when applied to carbon emissions (van den Bergh, Verbruggen (1999)) and gives no indication about the desirability of creating additional carbon sinks to absorb carbon from fossil fuels. What it rather intends is a ‘calculation experiment’ with the possible result of a measure for the ‘overuse’ (in that case due to fossil energy use) of the ecosystem in terms of ecosystem concepts. The information for policy makers lies not in the additional necessary carbon sinks in the form of forest land, but in the change in the indicator (*ha* land/person), if different mitigation options for policy (energy efficiency improvements, energy taxation, emission trading, etc.) are to be evaluated.

The treatment of the new emission absorption activity in the i-o model is analogue to the treatment of the abatement sector in Leontief's pollution model (Leontief (1970)). As it is an ecosystem activity I ignore possible transactions with the economic sphere as regarding to intermediate inputs, for example from industry. Instead the emission absorption activity has the same input structure as the autotroph compartment with primary inputs of a carbon stock (measured in land area or in PgC) and solar energy and the atmosphere sink input corresponding to the gross biomass production. Carbon is also released to the atmosphere by the emission absorption activity through respiration, which is accounted for in the atmosphere emission vector in final demand. The necessary primary inputs have been calculated with the data from Houghton, et al. (2001) for area, stocks and gross production of forests. The emission absorption sector is less productive in these terms than the total of autotroph organisms, because in total autotroph production the production of ocean phytoplankton is included, which has no corresponding stock of carbon or area of land in primary inputs. The productivity of the emission absorption sector is similar to that of agriculture in the first table of the carbon cycle. The production level of the emission absorption sector is determined by assuming that the whole anthropogenic carbon of 7,4 PgC (2,1 PgC land use change, 5,3 PgC emissions from fossil fuels) is absorbed, so that the initial situation of the carbon cycle with an decrease of atmospheric carbon of 5,1 PgC is reproduced.

Table 6: Physical Input-Output Table of Integrated Economy-Ecosystem Model Carbon Flows with Emission Absorption

The atmospheric balance now fulfills the condition $\mathbf{C_E} = \mathbf{C_S}$ as the carbon stock in the emission absorption activity increases by exactly these 7,4 PgC that are absorbed. This stock change of 7,4 PgC will be added in the next period to the 270 PgC initial stock of the emission absorption sector. Again this is an indication, that setting up a dynamic model within this accounting framework would represent a very promising line for future research. In a dynamic perspective it would also become clear that emission absorption of this type is a limited method to decrease atmospheric carbon, because the increase in the carbon pool over 20 or 30 years leads to a final equilibrium with gross production equal to respiration and zero net influence on atmospheric carbon. This could be taken into account by introducing depreciation rates on the stock, which would enter in the primary inputs vector and have an influence on the price solution of the model. These very promising and interesting possible extensions of the model lie beyond the scope of this paper.

Table 7: Technical Coefficients of the Economy-Ecosystem Model with Emission Absorption

The matrix of technical coefficients as well as the Leontief inverse can be calculated for the model with emission absorption to yield the solution for the hybrid (economic units and carbon units) output vector for given hybrid final demand. The hybrid system could be presented as a partitioned i-o model for economic units Q comprising the economic activities agriculture, industry/services and for carbon units C comprising the activities autotroph, heterotroph, detritus, anthropogenic carbon and emission absorption.

(8) $$\begin{pmatrix} Q \\ C \end{pmatrix} = \begin{bmatrix} I - A_{QQ} & -A_{QC} \\ -A_{CQ} & I - A_{CC} \end{bmatrix}^{-1} \begin{pmatrix} F_Q \\ F_C \end{pmatrix}$$

As before the vector of final demand of carbon, $\mathbf{F_C}$, can be decomposed in an endogenous part given by carbon emissions $\mathbf{C_E}$ and an exogenous part given by the carbon stock change vector $\mathbf{F_{ST}}$ and another exogenous component $\mathbf{F^*}$:

(9) $$\mathbf{F_C} = \mathbf{C_E} + \mathbf{F^*} + \mathbf{F_{ST}}$$

Renaming the respective parts of the inverse in equation (8) by $\mathbf{B_{QQ}}$, $\mathbf{B_{CQ}}$, $\mathbf{B_{QC}}$ and $\mathbf{B_{CC}}$ respectively we can again describe carbon emissions $\mathbf{C_E}$ as endogenous:

(10) $$\mathbf{C_E} = i' \mathbf{\hat{C}_E} [\mathbf{B_{CQ}} \mathbf{F_Q} + \mathbf{B_{CC}} \mathbf{F_C}]$$

Carbon sinks are as before given with:

(11) $$(C_S) = (c_S) \begin{bmatrix} I - A_{QQ} & -A_{QC} \\ -A_{CQ} & I - A_{CC} \end{bmatrix}^{-1} \begin{pmatrix} F_Q \\ F_C \end{pmatrix}$$

The balancing item to guarantee the condition $\mathbf{C_E} = \mathbf{C_S}$ in this model is the carbon stock change vector in final demand, $\mathbf{F_{ST}}$.

The system of equations (8) to (11) can be solved for given values of exogenous final demand **F*** and $\mathbf{F_{ST}}$. Changing the latter component would give an equilibrium, where more carbon is taken up from the atmosphere than in the initial carbon cycle without human perturbation.

2.2 ‘Ecological Value Added’ in an integrated model with emission absorption

The starting point for the analysis of the price model are as before the primary inputs in the activities. The main value added component is energy, which now enters as fossil energy in the economic activities and as solar energy in the ecosystem activities and in agriculture. For the economic activities value added is (as usually in i-o statistics) available in monetary terms. As has been noted above including depreciation rates for carbon stock and formulating a dynamic model would offer the option to include capital value added in the price model. In this static framework energy units and monetary units of primary inputs will be used alternatively to generate the solution of the i-o price model.

Table 8: Leontief-Inverse of the Economy-Ecosystem Model with Emission Absorption

The solution is given by multiplying the inverse **B** of equation (8) with the two value added row vectors of energy input, $\mathbf{v_E}$ and of monetary value added input, $\mathbf{v_M}$:

(12) $\mathbf{p_E} = \mathbf{v_E}\,\mathbf{B} \quad ; \quad \mathbf{p_M} = \mathbf{v_M}\,\mathbf{B}$

As *Table 8* shows the two price vectors differ in terms of activities for which prices exist. For energy value prices all activities (except anthropogenic carbon) have positive prices, for monetary prices autotroph production and emission absorption have zero prices. In the solution for energy values the price per unit of emission absorption is 62,5 10^3 PJ. Note that in the energy values solution the prices for agriculture and industry/services include fossil energy input.

The two price vectors can be used now to derive i-o tables in nominal values, one in energy values and the other in monetary units. In monetary units (*Table 10*) we arrive at the standard result of environmental accounting, that emission is costless, although the total accounting system shows considerable anthropogenic carbon emissions in the satellite system in physical units. Compared to that the table in energy values (*Table 9*) yields an output value of the emission absorption activity of 844 10^3 PJ, which equals the value added, as this activity has no intermediate input like the other autotroph organisms. This value added of emission absorption (**'ECOLOGICAL VALUE ADDED'**, **EVA**) shall be suggested here as a base for different sustainability indicators. Total final demand in energy values, which equals GDP or value added amounts to 7.644 10^3 PJ , the share of emission absorption over this total is about 11 percent. Excluding emission absorption value added from calculating total value added yields a share of 12,4 percent. One could also think of relating the emission absorption value added in 10^3 PJ to the economic value added in monetary units, which gives a number in the dimension of energy intensity. In our example this indicator has a value of 105,5:

	Final Demand	Emission Absorption
Energy Values	7.644	844
Monetary Units	800	–
Ecological Value Added, EVA, in percent of		
Energy Values	11	
Monetary Units	105,5	

Table 9: Input-Output Table of Integrated Economy-Ecosystem Model with Emission Absorption

At Prices in Energy Values

Table 10: Input-Output Table of Integrated Economy-Ecosystem Model with Emission Absorption

At Prices in Monetary Units

3. A simulation experiment: Technological change and 'Ecological Value Added'

In the following the results of a short simulation experiment shall be presented to describe the potential of the suggested EVA concept for empirical analysis and policy guidance. The 'Ecological Footprint' (EF) concept has been seriously challenged by critique about the limited use for empirical analysis and foundation for policies aiming at sustainable development. Part of this critique refers to the problems of the concept within the boundaries of a certain region and to the aggregation problems of different environmental problems to land use. Another part of the critique stresses too far the options of the indicator concept by assuming applied policies for sustainability within the concept. The first part of the critique is not applicable to the EVA concept suggested here as it is global and limits itself to the single environmental issue of anthropogenic carbon emission. The use of additional carbon sinks has been argued here with the processes of the carbon cycle in order to find an indicator for the 'overuse' of fossil energy. Again it shall be stated that the static accounting framework presented does not suggest that carbon sinks shall be used as a measure of sustainable policies. Instead it allows for a past year to derive the hypothetical additional carbon sinks, that would have been necessary to achieve a certain target of sustainability.

The EVA concept can have a comparative advantage over environmental accounting with satellite systems, if it contains more information for evaluating certain situations. For the simulation experiment I assume that due to sustainable policies the input of fossil energy per unit of output and equally the carbon emission decrease in both economic sectors by 20 percent. At the same time it is assumed that the economic impact is zero, so that these policies are carried out partly with 'double dividend' options and GDP does not change.

Table 11: Input-Output Quantity Model: Carbon Intensity minus 20 percent

First the i-o quantity model can be solved using the system of equations (8) to (11) under the condition that $\mathbf{C_E} = \mathbf{C_S}$ holds. This yields a decrease in the necessary emission absorption from an original output level of 13,5 PgC to 9,8 PgC. This is the direct effect of less anthropogenic carbon on the carbon balance.

At the same time the price model for energy values and monetary units can be solved according to (12). Due to the decrease of carbon and energy intensity of the economic sectors the value added of total energy has now also decreased yielding lower prices in energy values for agricultural and industrial products. Again the resulting i-o quantity model can be multiplied along the rows by the corresponding prices to give i-o tables in nominal values.

Table 12: Input-Output Model: Carbon Intensity minus 20 percent

At Prices in Energy Values

Table 13: Input-Output Model: Carbon Intensity minus 20 percent

At Prices in Monetary Units

As far as the economic side is concerned, nothing has changed and GDP remains at 800 monetary units. The decrease in the necessary emission absorption output level from 13,5 PgC to 9,8 PgC leads to a decrease in the ecological value added (EVA) to 615 10^3 PJ compared to 844 10^3 PJ in the base model. The proposed sustainability indicators drop significantly to 8,1 and 76,8 percent respectively. This additional information of the EVA might be seen as an advantage over traditional environmental accounting with satellite accounts.

	Final Demand	Emission Absorption
Energy Values	7.597	615
Monetary Units	800	–
Ecological Value Added, EVA, in percent of		
Energy Values	8,1	
Monetary Units	76,8	

Conclusions

This paper has shown a synthesis of different approaches in order to propose a valuation concept for ‘overuse’ of the ecosystem by fossil energy use. Physical i-o tables of the carbon cycle only and including a two activity (example) economy as well as including emission absorption of the ecosystem are derived.

Introducing energy as the value added component in the ecosystem, the flows are expressed in ‘energy values’. As additional carbon sinks for emission absorption need solar energy input (= value added), an ‘ecological value added’ concept is suggested to calculate the costs of anthropogenic carbon emissions. A simulation experiment shows the comparative advantage of the ‘ecological value added’ concept over environmental accounting with satellite accounts for a situation, where emissions decrease due to technology changes without a change in GDP.

The concept presented is only a static accounting framework described as an i-o model and is only used to derive sustainability indicators. It might be helpful as an additional indicator for policy simulations, if it is integrated in E3 models. Actually one could think of using this approach as a framework for the usually less developed environment-economy links in E3 models.

Table1: Physical Input-Output Table of the Ecosystem: Carbon Flows

						FINAL DEMAND				
								ENVIRONMENT		
INTERMEDIATE CONSUMPTION	Autotroph	Heterotroph	Detritus	Agriculture	INPUT, Z(j)	Human Consumption	Carbon Stock	Soil, Ocean	Atmosphere	OUTPUT
Autotroph		22,6	64,5		87,1	5,0		2,7	117,8	212,6
Heterotroph			3,0		3,0	1,0			26,7	30,7
Detritus		6,0			6,0			1,0	60,5	67,5
Agriculture		2,1			2,1	2,0			4,1	8,2
ENVIRONMENT										
Soil, Ocean (Sink)							5,1		0,4	5,5
Atmosphere (Sink)	212,6			8,2	220,8	−8,0	−5,1	1,8		209,5
INPUT, Z(i)	212,6	30,7	67,5	8,2			0,0	5,5	209,5	
PRIMARY INPUT										
Stock (Carbon)	2.051			169				38.000	730	
Stock (Area, 10^6 ha)	13.590			1.350						
Solar Energy (10^3 PJ)	6.795			675						
OUTPUT	212,6	30,7	67,5	8,2						

Table 2: Technical Coefficients of the Ecosystem Model

	Autotroph	Heterotroph	Detritus	Agriculture
Autotroph	0	0,7371	0,9551	0
Heterotroph	0	0	0,0444	0
Detritus	0	0,1954	0	0
Agriculture	0	0,0684	0	0
ENVIRONMENT				
Soil, Ocean (Sink)	0	0	0	0
Atmosphere (Sink)	1	0	0	1
INPUT, Z				
PRIMARY INPUT				
Stock (Carbon)	9,6	0	0	20,6
Stock (Area, 10^6 ha)	63,9	0	0	164,6
Solar Energy (10^3 PJ)	32,0	0	0	82,3
Value Added, v	32,0	0	0	82,3

Table 3: Leontief-Inverse of the Ecosystem Model

	Autotroph	Heterotroph	Detritus	Agriculture
Autotroph	1	0,9318	0,9965	0
Heterotroph	0	1,0088	0,0448	0
Detritus	0	0,1971	1,0088	0
Agriculture	0	0,0690	0,0031	1
	1	2,2101	2,0702	1
ENVIRONMENT				
Soil, Ocean (Sink)	0	0	0	0
Atmosphere (Sink)	1	0	0	1
PRIMARY INPUT				
Stock (Carbon)	9,6	0	0	20,6
Stock (Area, 10^6 ha)	63,9	0	0	164,6
Solar Energy (10^3 PJ)	32,0	0	0	82,3
Value Added, v	32,0	0	0	82,3
Prices, p	32,0	35,5	32,1	82,3

Table 4: Ecosystem Model (Carbon) in 'Energy Values'

INTERMEDIATE CONSUMPTION	Autotroph	Heterotroph	Detritus	Agriculture	INPUT, Z(j)	Human Consumption	Soil, Ocean	Atmo-sphere	Carbon Stock	OUTPUT
Autotroph		723,3	2.060,6		2.783,8	159,8	86,3	3.765,1	0	6.795,0
Heterotroph			106,4		106,4	35,5	0	946,9	0	1.088,7
Detritus		192,6			192,6	0	32,1	1.942,1	0	2.166,8
Agriculture		172,9			172,9	164,6	0	337,5	0	675,0
TOTAL	0	1.088,8	2.166,9	0	3.255,7	359,9	118,4	6.991,5	0	
Value Added	6.795,0	0	0	675,0						
OUTPUT	6.795,0	1.088,8	2.166,9	675,0						

Table 5: Physical Input-Output Table of Integrated Economy-Ecosystem Model: Carbon Flows without Emission Absorption

								FINAL DEMAND					
										ENVIRONMENT		ECONOMIC OUTPUT, Q	CARBON OUTPUT, C
INTERMEDIATE CONSUMPTION	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	INPUT, Z(j)	Final Demand	Carbon Stock	Soil, Ocean	Atmosphere		
Agriculture	0	20		15			35	40			6,2	75	
Industry	35	100					135	120			3,7	255	
Autotroph				22,6	64,5		87,1	5		2,7	117,8		212,6
Heterotroph					3		3	1			26,7		30,7
Detritus				6			6			1	60,5		67,5
Anthropogenic Carbon	6,2	3,7					9,9						9,9
ENVIRONMENT													
Soil, Ocean (Sink)									5,1		0,4		5,5
Atmosphere (Sink)	8,2		212,6				220,8	−9,6	−5,1	1,8			207,9
INPUT, Z(i)									0,0	5,5	215,3		
PRIMARY INPUT													
Stock (Carbon)	169		2051	0	0					38.000	730		
Stock (Area, 10^6 ha)	1.350		13.590	0	0								
Solar Energy (10^3 PJ)	675		6795	0	0								
Value Added (Money)	100	700											
Fossil Energy (10^3 PJ)	64	110											

Table 6: Physical Input-Output Table of Integrated Economy-Ecosystem Model Carbon Flows with Emission Absorption

									FINAL DEMAND					
										ENVIRONMENT			ECONOMIC OUTPUT, Q	CARBON OUTPUT, C
INTERMEDIATE CONSUMPTION	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	INPUT, Z(j)	Final Demand	Carbon Stock	Soil, Ocean	Atmosphere		
Agriculture	0	20		15				35	40			6,2	75	
Industry	35	100		0				135	120			3,7	255	
Autotroph				22,6	64,5			87,1	5		2,7	117,8		212,6
Heterotroph					3			3	1			26,7		30,7
Detritus				6				6			1	60,5		67,5
Anthropogenic Carbon	6,23	3,68						9,91						9,91
Emission Absorption										7,4		6,075		13,475
ENVIRONMENT														
Soil, Ocean (Sink)										5,1		0,4		5,5
Atmosphere (Sink)	8,2		212,6				13,5	234,3	−9,59	−5,1	1,8	0		221,41
INPUT, Z(i)										7,4	5,5	221,375		
PRIMARY INPUT														
Stock (Carbon)	169		2.051				270							
Stock (Area, 106 ha)	1.350		13.590				1.687,5							
Solar Energy (103 PJ)	675		6.795				843,75							
Value Added (Money)	100	700												
Fossil Energy (103 PJ)	63,9	110,4												
Total Energy (103 PJ)	738,9	110,4	6.795	0	0	0	843,75							
OUTPUT, Q/C	75	255	212,6	30,7	67,5	9,91	13,5							

Table 7: Technical Coefficients of the Economy-Ecosystem Model with Emission Absorption

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption
Agriculture	0,0000	0,0784	0,0000	0,4886	0,0000	0,0000	0,0000
Industry	0,4667	0,3922	0,0000	0,0000	0,0000	0,0000	0,0000
Autotroph	0,0000	0,0000	0,0000	0,7362	0,9556	0,0000	0,0000
Heterotroph	0,0000	0,0000	0,0000	0,0000	0,0444	0,0000	0,0000
Detritus	0,0000	0,0000	0,0000	0,1954	0,0000	0,0000	0,0000
Anthropogenic Carbon	0,0831	0,0144	0,0000	0,0000	0,0000	0,0000	0,0000
Emission Absorption	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
ENVIRONMENT							
Soil, Ocean (Sink)	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Atmosphere (Sink)	0,1	0,0	1,0	0,0	0,0	0,0	1,0
INPUT, Z(i)							
PRIMARY INPUT							
Stock (Carbon)	2,3	0,0	9,6	0,0	0,0	0,0	20,0
Stock (Area, 106 ha)	18,0	0,0	63,9	0,0	0,0	0,0	125,0
Solar Energy (103 PJ)	9,0	0,0	32,0	0,0	0,0	0,0	62,5
Value Added (Money)	1,3	2,7	0,0	0,0	0,0	0,0	0,0
Fossil Energy (103 PJ)	0,9	0,4	0,0	0,0	0,0	0,0	0,0
Total Energy (103 PJ)	9,9	0,4	32,0	0,0	0,0	0,0	62,5

Table 8: Leontief-Inverse of the Economy-Ecosystem Model with Emission Absorption

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption
Agriculture	1,0641	0,1373	0,0000	0,5244	0,0233	0,0000	0,0000
Industry	0,8170	1,7507	0,0000	0,4027	0,0179	0,0000	0,0000
Autotroph	0,0000	0,0000	1,0000	0,9310	0,9969	0,0000	0,0000
Heterotroph	0,0000	0,0000	0,0000	1,0088	0,0448	0,0000	0,0000
Detritus	0,0000	0,0000	0,0000	0,1971	1,0088	0,0000	0,0000
Anthropogenic Carbon	0,1002	0,0366	0,0000	0,0494	0,0022	1,0000	0,0000
Emission Absorption	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	1,0000
Prices, Energy Values	10,8	2,1	32,0	35,1	32,1	0,0	62,5
Prices, Money	3,7	5,0	0,0	1,8	0,1	0,0	0,0

Table 9: Input-Output Table of Integrated Economy-Ecosystem Model with Emission Absorption

At Prices in Energy Values

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	FINAL DEMAND	OUTPUT, Q/C
Agriculture	0,0	216,7	0,0	162,6	0,0	0,0	0,0	433,5	812,7
Industry	73,9	211,0	0,0	0,0	0,0	0,0	0,0	253,2	538,1
Autotroph	0,0	0,0	0,0	722,3	2.061,5	0,0	0,0	4.011,2	6.795,0
Heterotroph	0,0	0,0	0,0	0,0	105,3	0,0	0,0	972,2	1.077,4
Detritus	0,0	0,0	0,0	192,6	0,0	0,0	0,0	1.974,2	2.166,7
Anthropogenic Carbon	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Emission Absorption	0,0	0,0	0,0	0,0	0,0	0,0	0,0	843,8	843,8
TOTAL	73,9	427,8	0,0	1.077,5	2.166,8	0,0	0,0	7.644,2	11.389,9
ENVIRONMENT									
Soil, Ocean (Sink)	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
Atmosphere (Sink)	8,2	0,0	212,6	0,0	0,0	0,0	13,5		
VALUE ADDED									
Total Energy (103 PJ)	738,9	110,4	6.795,0	0,0	0,0	0,0	843,8		
OUTPUT, Q/C	812,8	538,2	6.795,0	1.077,5	2.166,8	0,0	843,8		

Table 10: Input-Output Table of Integrated Economy-Ecosystem Model with Emission Absorption

At Prices in Monetary Units

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	FINAL DEMAND	OUTPUT, Q/C
Agriculture	0,0	73,2	0,0	54,9	0,0	0,0	0,0	146,5	274,6
Industry	174,6	498,9	0,0	0,0	0,0	0,0	0,0	598,7	1.272,2
Autotroph	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Heterotroph	0,0	0,0	0,0	0,0	5,4	0,0	0,0	50,0	55,4
Detritus	0,0	0,0	0,0	0,5	0,0	0,0	0,0	4,9	5,4
Anthropogenic Carbon	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Emission Absorption	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
TOTAL	174,6	572,1	0,0	55,4	5,4	0,0		800,0	1.607,6
ENVIRONMENT									
Soil, Ocean (Sink)	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
Atmosphere (Sink)	8,2	0,0	212,6	0,0	0,0	0,0	13,5		
VALUE ADDED									
Monetary Units	100,0	700,0	0,0	0,0	0,0	0,0	0,0		
OUTPUT, Q/C	274,6	1.272,1	0,0	55,4	5,4	0,0	0,0		

Table 11: Input-Output Quantity Model: Carbon Intensity minus 20 percent

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	OUTPUT, Q/C	TOTAL FINAL	FINAL DEMAND Final Demand, etc.	Atmosphere	Carbon Stock
Agriculture	1,1	0,1	0,0	0,5	0,0	0,0	0,0	75,0	40,0	40,0	5,0	0,0
Industry	0,8	1,8	0,0	0,4	0,0	0,0	0,0	255,0	120,0	120,0	3,0	0,0
Autotroph	0,0	0,0	1,0	0,9	1,0	0,0	0,0	212,2	125,3	7,7	117,6	0,0
Heterotroph	0,0	0,0	0,0	1,0	0,0	0,0	0,0	30,6	27,6	1,0	26,6	0,0
Detritus	0,0	0,0	0,0	0,2	1,0	0,0	0,0	67,4	61,4	1,0	60,4	0,0
Anthropogenic Carbon	0,1	0,0	0,0	0,0	0,0	1,0	0,0	7,9	0,0	0,0	0,0	0,0
Emission Absorption	0,0	0,0	0,0	0,0	0,0	0,0	1,0	9,8	9,8	0,0	4,4	5,4
ENVIRONMENT												
Soil, Ocean (Sink)	0,0	0,0	0,0	0,0	0,0	0,0	0,0					
Atmosphere (Sink)	0,1	0,0	1,0	0,0	0,0	0,0	1,0		−9,6			
OUTPUT, Q/C	75,0	255,0	212,2	30,6	67,4	7,9	9,8					

Table 12: Input-Output Model: Carbon Intensity minus 20 percent

At Prices in Energy Values

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	FINAL DEMAND	OUTPUT, Q/C
Agriculture	0,0	211,7	0,0	158,4	0,0	0,0	0,0	423,4	793,4
Industry	67,7	193,5	0,0	0,0	0,0	0,0	0,0	232,2	493,5
Autotroph	0,0	0,0	0,0	720,8	2.057,4	0,0	0,0	4.004,4	6.782,7
Heterotroph	0,0	0,0	0,0	0,0	104,7	0,0	0,0	966,7	1.071,3
Detritus	0,0	0,0	0,0	192,2	0,0	0,0	0,0	1.970,0	2.162,2
Anthropogenic Carbon	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Emission Absorption	0,0	0,0	0,0	0,0	0,0	0,0	0,0	614,5	614,5
TOTAL	67,7	405,2	0,0	1.071,3	2.162,2	0,0	0,0	7.596,8	11.303,1
ENVIRONMENT									
Soil, Ocean (Sink)	8,2	0,0	212,2	0,0	0,0	0,0	9,8		
Atmosphere (Sink)	0,0	0,0	0,0	0,0	0,0	0,0	0,0		
VALUE ADDED									
Total Energy (103 PJ)	725,7	88,3	6.782,7	0,0	0,0	0,0	614,5		
OUTPUT, Q/C	793,4	493,5	6.782,7	1.071,3	2.162,2	0,0	614,5		

Table 13: Input-Output Model: Carbon Intensity minus 20 percent

At Prices in Monetary Units

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Anthropogenic Carbon	Emission Absorption	FINAL DEMAND	OUTPUT, Q/C
Agriculture	0	73	0	55	0	0	0	146	274
Industry	175	499	0	0	0	0	0	599	1272
Autotroph	0	0	0	0	0	0	0	0	0
Heterotroph	0	0	0	0	5	0	0	50	55
Detritus	0	0	0	0	0	0	0	5	5
Anthropogenic Carbon	0	0	0	0	0	0	0	0	0
Emission Absorption	0	0	0	0	0	0	0	0	0
TOTAL	175	572	0	55	5	0		800	1.607
ENVIRONMENT									
Soil, Ocean (Sink)	8	0	212	0	0	0	10		
Atmosphere (Sink)	0	0	0	0	0	0	0		
VALUE ADDED									
Monetary Units	100	700	0	0	0	0	0	1	
OUTPUT, Q/C	274	1.272	0	55	5	0	0		

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