‘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, allows to calculate ecosystem prices expressed in ‘energy values’. Linking the ecosystem with the economy in an integrated input-output model then allows to calculate prices of economic activities and of ecosystem activities. In analogy to the 'Ecological Footprint', where productive land is needed to absorb anthropogenic emissions, in this integrated input-output model additional carbon sinks are introduced for emission absorption. These carbon sinks need solar energy input, i.e. ‘ecological value added’. Emission absorption as well as GDP therefore become activities valued in the numeraire of the integrated system, i.e.'energy values'. From that sustainability indicators can be derived.

Key words: ecosystem pricing, input-output, climate change

JEL classification: Q30, Q32, Q01

Acknowledgements: Invaluable research assistance for this paper has been provided by Martina Agwi. I also would like to thank three anonymous referees for suggestions and comments.

1. Introduction

The crucial and still unresolved issue in the debate on indicators for sustainability and environmental accounting is the 'valuation problem'. Ecosystem services and contributions as well as anthropogenic influences on the eccosystem had to be valued in economic terms. There are different approaches 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 stemming from different measurement methods differ considerably. Environmental accounting in the last decade has bypassed this 'valuation problem' and dedicated its research efforts to collecting physical data about emissions and thereby developing ‘satellite’ accounts to national accounting.

This paper tries a synthesis of two approaches in order to propose a valuation concept for anthropogenic carbon emissions. The scope of the paper is therefore limited as far as environmental problems dealt with are concerned. The synthesis combines a concept of ecosystem pricing in an integrated ecosystem – economy model with the basic idea of limited carrying capacity of the ecosystem. The latter is introduced by an emission absorption function of the ecosystem expressed in terms of natural ressources necessary to absorb anthropogenic emissions like in the 'Ecological Footprint' concept.

Starting point is the existing literature on ecosystem pricing and on the 'Ecological Footprint' concept. Then an input -output model of the carbon and energy flows in an example ‘global ecosystem' is constructed, using the most recent data for the global carbon cycle from Houghton, et.al. (2001). Applying the ideas of Costanza (1991), Hannon (1991, 1995) and Hannon, et.al. (1986), the flows can be converted into 'energy values' using only solar energy as the the numeraire and therefore as the value added component.

The physical input - output table of the carbon cycle is then enlarged by linking it to a two activity (example) economy yielding an integrated system in hybrid units. Taking up the original idea of the 'Ecological Footprint' concept in a further step 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)). Carbon absorption by this activity needs additional primary inputs (forest land, solar energy). Therefore the input -output quantity and price model can be presented with a solution for physical quantities in different units and prices in commensurable 'energy values' (solar energy for the ecosystem and fossil energy for the economy). That allows to calculate the 'Ecological Value Added' of a certain amount of emission absorption. One possible indicator for sustainability might then be the relationship of 'Ecological Value Added' measured in energy values to total GDP or similar aggregates of net output or net human demand measured in energy values.

The final section of the paper describes the results of a simulation experiment concerning greenhouse gas reduction policies. We start from results of recent model simulations of domestic emission reduction measures in the U.S. (Rose, Oladosu (2002)), where carbon emissions decrease significantly due to mitigation policy (emission trading) and economic activity (GDP) suffers. This simulation clearly reveals the comparative advantage of the ‘Ecological Value Added’, where both results can be accounted and therefore compared in commensurable 'energy values'.

2. Ecosystem pricing

The research on sustainability has begun to take into account the relevant ecosystem features and the amount of human perturbation by economic activity. A comprehensive approach of ‘ecosystem services’ including resource use, value of utility, carrying capacity for absorption of emissions and stability due to biodiversity, has been laid down by Norberg (1999).

Another line of research in ecological economics described by van den Bergh (1996) as the ‘biophysical’ approach 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. Also linking of the ecosystem to economic activity is considered in this line of research. Costanza (1991) proposes a hybrid ecosystem-economy model in a make/use system and derives the Leontief inverse and thereby total energy embodied in each commodity ('ecological interdependence factors'), which he proposes as a measure of 'ecological prices'.

Two recent papers have developed the concept of ecosystem pricing even further. Klauer (2000) uses Koopmans linear production model to derive a price solution in an ecosystem model, where in analogy to national accounting primary factors as well as gross and net output are differentiated. Hannon (2001) sets up a full hybrid ecosytem-economy i-o model in order to derive net output and input of both systems. Net input of the ecosystem is represented by metabolism as the 'cost of running the ecosystem' (Hannon (2001), p.22). Values for these inputs of metabolism are introduced through contingent valuation in the ecosystem.

This short literature overview shows that ecosystem pricing is an established line of research and that i-o models of the ecosystem linked to the economy and the total energy content as the measure of value are the main concepts. Another line of research (for example Klauer (2000)) refuses to have only one value component in ecosystem pricing. In this study we have decided to apply the concept of the energy content of commodities as the value measure in an i-o model. We argue, that using this value measure in first instance just serves as a ‘numeraire’, but also is a consistent value concept for anthropogenic emissions, as energy is needed to drive the bio-geochemical cycles in ecosystems.

3. Carrying capacity and 'Ecological Footprint'

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. The EF concept has also been extended in combination with i-o analysis (Bicknell, et al. (1998)) to show the huge analytical potential of the approach.

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 of converting the ‘excessive use’ of the ecosystem by fossil energy use beyond the carrying capacity into additional forest land (i.e. carbon sinks), that would have been necessary to absorb the carbon emissions. It has been argued, that aggregating all environmental problems into the land use dimension using conversion factors ignores the complexity of ecosystems and the interdependencies between different environmental impacts.

Another point of the critique concerns the spatial dimension of the EF if applied to countries or small populations (van den Bergh, Verbruggen (1999)). 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 ‘excessive use’ (in that case due to fossil energy use) beyond the carrying capacity of the ecosystem in terms of ecosystem concepts. In the case of carbon emissions 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, emissions trading, etc.) are to be evaluated. We apply the original idea of the EF concept in this paper to derive a measure for the necessary volume of ecosystem resources for emission absorption. We introduce that into the i-o model as an additional absorption activity like in Leontief’s pollution model (Leontief (1970)).

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

Starting point for the i-o model outlined here are the basic features of the relevant ecosystem activities, that contribute to the global carbon cycle. We limit ourselves to the chemical cycle of carbon without dealing with other important materials of the ecosystem.

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.

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 i-o system has been taken mainly from Hannon (1973), Odum (1983), Giampetro, Pimentel (1991) and Odum (1991).

The ecosystem includes the following throphical levels: autotroph organisms, i.e. plants, and heterotroph organisms (herbivores, predators, the human being, etc.) and detritus, where biomass is converted into CO_2 via fermentation by bacteria. Carbon flows are represented by photosynthesis and respiration. Photosynthesis describes the process of <u>gross production</u> of the ecosystem by plants, by which solar energy is absorbed. The <u>solar constant</u> 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 <u>net production</u>.

>>>> Figure 1: The global carbon cycle

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. From Houghton, et al. (2001) we took data on biomass production in PgC, on the distribution of land area across different types of ecosystems and the corresponding carbon stock. Figure 1 describes the most important gross flows in the global carbon cycle in PgC (petagramm Carbon) in a stylized manner (without the 'human' activity of agriculture within the autotroph production), which entered in the physical i-o table (Table 1). These data have been combined with assumptions about the biomass flows between autotroph, heterotroph and detritus.

>>>>> Table1: Physical input-output table of the ecosystem: carbon flows

Table 1 shows an input – output system of the carbon cycle in physical units. This system is essentially ‘anthropocentric’, as the last use (= final demand) of all activities is human consumption. The activities are: autotroph, heterotroph, detritus and the environmental media soil/ocean. The atmosphere is included as an environmental media between the level of activities and primary inputs and serves as the balancing item between inputs and outputs of carbon. The negative row of carbon emissions to the atmosphere is equivalent to a postive column vector (output) of a carbon flow to the atmosphere, which represents joint production of carbon release to the atmosphere.

As primary inputs the stocks necessary for production in carbon and in area dimensions are included and solar energy is chosen as the ‘value added’ component. Final demand comprises human consumption of carbon, that is used up in respiration (6 PgC) representing the emission element of final demand. The other final demand component is stock change in carbon. Without human perturbation the natural global carbon cycle shows a carbon uptake of soil and ocean of about 5,1 PgC (3,7 PgC land uptake and 1,4 PgC inert and dissolved carbon in the ocean). For the numbers used here without human perturbation the atmosphere would ‘loose’ 5,1 PgC of carbon concentration. This could be described as an ‘oversustainable’ situation, as human activity could use up these 5 PgC for fossil energy use. The (negative) uptake of atmosphere and the inert carbon stock increase balance out, so that the vector of carbon stock change only contains zero elements across all sectors considered. The atmospheric balance is given by sink uptake through autotroph, emissions from all sectors and flows between environmental media (soil/ocean, atmosphere).

The matrix of technical coefficients **A** as well as the Leontief inverse $[\mathbf{I} - \mathbf{A}]^{-1}$ can be calculated from the i-o table comprising the four sectors. This gives the traditional representation of the i-o model:

$$\mathbf{Q} = [\mathbf{I} - \mathbf{A}]^{-1}\mathbf{F} \qquad \mathbf{F} = \mathbf{F_H} + \Delta\,\mathbf{S} \tag{1}$$

with output vector **Q**, and final demand vector **F** consisting of human consumption $\mathbf{F_H}$ and stock change $\Delta\mathbf{S}$. Primary inputs can be divided into a row vector of stocks **S** and energy , which will be used as the value added component, $\mathbf{V_E}$. The existence of different primary inputs seems to make it an arbitrary decision to use solar energy as the relevant factor of value added like money value added in an economic system. One could think of using a linear programming model for modeling the input of primary factors. On the other hand a similar issue of 'values and prices' has also been intensively discussed in economic theory. Refering to this debate the concept of solar energy as the relevant value added component ('numeraire') can be seen as the corresponding concept to the theory of labour value in economic theory. The main argument in favour of solar energy as the relevant value added here is that it is the necessary input to drive the bio-geochemical carbon cycle. An extension of this approach could attempt to valuate the stock components within primary inputs in terms of this 'numeraire' of solar energy.

In a dynamic model we would take into account the relationship between the vector $\mathbf{\Delta S}$ (stock changes) and the primary input stocks $\mathbf{S}$:

$$\mathbf{S_t} = \mathbf{S_{t-1}} + \mathbf{\Delta S_t} \tag{2}$$

$$\mathbf{S_{t-1}} = \mathbf{s_{t-1}}\,[\,\mathbf{I} - \mathbf{A}]^{-1}\,\mathbf{F_{t-1}} \tag{3}$$

These stocks in one period would be given by the technology represented by the row vector of stock inputs per unit of output , $\mathbf{s}$, which changes continously over time through additions to stocks, $\mathbf{\Delta S}$. We will not deal with dynamics in this study and only look at the static framework represented in (1).

We can now also link the atmosphere flows of sinks and emissions by input and emission coefficients to final demand:

$$\mathbf{C_S} = \mathbf{c_S} \, [\mathbf{I} - \mathbf{A}]^{-1} \, \mathbf{F} \tag{4}$$

$$\mathbf{C_E} = \mathbf{c_E} \, [\mathbf{I} - \mathbf{A}]^{-1} \, \mathbf{F} + \mathbf{C_{EF}} \tag{5}$$

with $\mathbf{C_S}$ as a scalar of total carbon sinks and $\mathbf{c_S}$ as a row vector of carbon sink coefficients per unit of output, $\mathbf{C_E}$ as a scalar of total carbon emissions and $\mathbf{c_E}$ as a row vector of carbon emission coefficients per unit of output. Equation (5) also takes into account, that part of the emissions stems directly from final demand activities ($\mathbf{C_{EF}}$). 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 $\mathbf{C_E} = \mathbf{C_S}$.

The i-o price model can be used to derive ‘energy value prices’ $\mathbf{p_E}$, if we take the row vector of solar energy input $\mathbf{v_E}$ with elements $\mathbf{V_E}/\mathbf{Q}$ (= solar energy input per unit of output) as the value added component of the system:

$$\mathbf{p_E} = \mathbf{v_E} \, [\mathbf{I} - \mathbf{A}]^{-1} \tag{6}$$

This finally allows to derive the i-o table in energy values, where all transactions along the rows are transformed by the corresponding ‘energy value-price’. We therefore reproduce the results of Costanza (1991) and Hannon (1991) concerning ecosystem pricing and combine them with a solution for the athmospheric carbon balance derived from the quantity model.

5. 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. This type of integrated model includes the ecosystem capacity of forests, that <u>would have been necessary</u> to absorb anthropogenic carbon emissions. This activity is introduced as an abatement activity as in Leontief's original pollution model (Leontief (1970)). The physical i -o table of the ecosystem is extended in a first step to include two economic activities, namely agriculture and industry/services.

>>>>> Table 2: Physical input-output table of integrated economy-ecosystem model

The total anthropogenic emission of carbon due to fossil fuel use and to land use change (5,3 PgC) are distributed among agriculture, industry and final demand. Without emission absorption anthropogenic additional emissions are not compensated by other carbon stock changes and therefore stay in the atmosphere as additional carbon uptake, so that $\mathbf{C_E} > \mathbf{C_S}$. Such a model could be formulated to have carbon stock as the balancing item, so that the atmosphere would then take up carbon and the concentration would rise. 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 <u>theoretically necessary autotroph production capacity</u> 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 <u>anthropogenic</u> measures. It must be repeated that with assuming the introduction of the <u>theoretically necessary autotroph production capacity</u> nothing is said about a sustainable scenario or target and about desirability of reforestation as carbon mitigation policy. The critizism on the the aggregation bias of the EF, when applied to all environmental problems together is also not valid in this singular case of carbon emissions.

The new emission absorption activity is an ecosystem activity, which (by assumption) has no transactions with the economic sphere (for example intermediate inputs 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 row. 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. Additionally we introduce as primary inputs solar energy used in the ecosystem as before and energy inputs in industry/services and in agriculture (assuming that it is mainly fossil energy). In the economic system (agriculture, industry/services) we can further introduce the traditional value added measured in money units.

The production level of the emission absorption sector is determined by assuming that the whole anthropogenic carbon of 5,3 PgC is absorbed, so that the initial situation of the carbon cycle with an decrease of atmospheric carbon of 5,1 PgC is reproduced. The atmospheric balance fulfills the condition $\mathbf{C_E} = \mathbf{C_S}$ as the carbon stock in the emission absorption activity increases by exactly these 5,3 PgC that are absorbed. This stock change of 5,3 PgC will be added in the next period to the 270 PgC initial stock of the emission absorption sector.

The matrix of technical coefficients as well as the Leontief inverse can be calculated for this model 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, soil/ocean and emission absorption:

$$\left(\frac{Q}{C}\right)=\left[\frac{I-A_{QQ}}{-A_{CQ}}\frac{-A_{QC}}{I-A_{CC}}\right]^{-1}\left(\frac{F_Q}{F_C}\right) \tag{7}$$

As in Costanza (1991) and Hannon (2001) this hybrid system is set up with different unit measures in each row and even within **Q** different units for agriculture and industry/services might be used. The final demand vector comprises human consumption $\mathbf{F_H}$ in units of **Q** and **C** now and stock changes $\mathbf{\Delta S}$, which we explicitly only treat in units of **C**:

$$\left(\frac{F_Q}{F_C}\right)=\left(\frac{F_{HQ}}{F_{HC}}\right)+\left(\frac{0}{\Delta S_C}\right) \tag{8}$$

The dynamic relationship between the stocks **S** in primary inputs and the stock change vector of final demand $\mathbf{\Delta S_C}$ could again be considered in a dynamic model (compare (2)). This would represent a very promising line for future research, as it would 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. The dynamic model had to be extended beyond (2) therefore by introducing depreciation rates on the stock. All these promising possible extensions of the model lie beyond the scope of this paper.

We can now again describe total carbon emissions $\mathbf{C_E}$ as given for a given row vector of emission coefficients $\mathbf{c_E}$ (in the economic system (**Q**) and in the ecosystem (**C**)) plus the sum of emissions linked to final demand $\mathbf{C_{EF}}$:

$$C_E = (c_{EQ}\, c_{EC})\left[\frac{I - A_{QQ}}{-A_{CQ}} \; \frac{-A_{QC}}{I - A_{CC}}\right]^{-1}\left(\frac{F_Q}{F_C}\right) + C_{EF} \qquad (9)$$

Carbon sinks are then given with:

$$C_S = (c_{SQ}\, c_{SC})\left[\frac{I - A_{QQ}}{-A_{CQ}} \; \frac{-A_{QC}}{I - A_{CC}}\right]^{-1}\left(\frac{F_Q}{F_C}\right) \qquad (10)$$

The balancing item to guarantee the condition $\mathbf{C_E} = \mathbf{C_S}$ in this model is final demand for emission absorption activity within $\mathbf{F_C}$ (as in Leontief´s original pollution model).

The starting point for the analysis of the price model are the primary inputs in the activities with energy as the main value added component comprising fossil energy in the economic activities and solar energy in the ecosystem activities and in agriculture. For the economic activities value added is also available in monetary terms. In the dynamic framework with depreciation rates we had another component of 'carbon stock input' as capital value added.

>>>>> Table 3: Leontief-inverse of the economy-ecosystem model

The solution is given by multiplying the inverse of equation (7) with the row vectors of two value added components of energy input, $\mathbf{v_E}$ (comprising solar energy **S** and fossil energy **F**):

$$(p_E) = (v_{EF}\; v_{ES}) \begin{bmatrix} I - A_{QQ} & -A_{QC} \\ -A_{CQ} & I - A_{CC} \end{bmatrix}^{-1} \qquad (11)$$

The resulting price vector in 'energy values' (10^3 PJ) is:

Agriculture	13.8
Industry	2.5
Autotroph	71.7
Heterotroph	4313.3
Detritus	1929.8
Soil/Ocean	416.3
Emission Absorption	113.6

The price solution of the model allows to calculate the price per unit of emission absorption (113.6 10^3 PJ). The price vector can be used to derive an i-o table in energy values. This table yields an output value of the emission absorption activity of 606 10^3 PJ, which equals value added as well as final demand, 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.

>>>>> Table 4: Input-output table of integrated economy-ecosystem model, at prices in energy values

The EVA of 606 10^3 PJ can now be related to different aggregates of total value added (V.A.) or final demand (F.D.). At the value added side of the system we can identify the following aggregates:

V.A. of the economy : 849 10^3 PJ
V.A. of the ecosystem : 7401 10^3 PJ

That sums up to a total value added of 8250 10^3 PJ, with a share of EVA amounting to 7.3 percent. If we are interested in the burden of economic activity for the ecosystem, we should probably relate EVA to the ecosystem value added without economic activity and emission absorption, which is simply the value added of autotrophs: 6795 10^3 PJ. This would give us a share of EVA of 9 percent.

On the final demand side of the system we can identify the following aggregates:

Human F.D.: 5521 10^3 PJ
F.D. of the ecosystem : 2730 10^3 PJ

Total final demand equals total net product (V.A.) of 8250 10^3 PJ as required by the identities of the system. Here we could think of relating EVA to total human final demand, which could be seen as the ultimate goal of economic activity. This would give us a share of EVA of about 11 percent.

We will not suggest any ultimate 'measure of sustainability' in this paper, but just want to show the potential of the suggested approach to derive several indicators from a system, where economic and ecosystem activities are valued in commensurable units.

6. A simulation experiment: Greenhouse gas reduction policies 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. As has been stated above, this study attempts a synthesis between the concept of ecosystem pricing and the basic idea of the 'Ecological Footprint' approach in order to derive sustainability indicators. This synthesis of concepts shall be shown to exhibit a comparative advantage compared to the other concepts.

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 the critique stresses too far the options of the indicator concept by assuming applied policies for sustainability within the concept. It must be repeated here that the static accounting framework of the EF as well as of the EVA concept 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 also starts from this carbon sink calculations but further derives a valuation of this additional necessary ecosystem activity. This valuation stems from applying ecosystem pricing to an integrated economy-ecosystem i-o model.

For the simulation experiment we start from a recent example of the impact of domestic greenhouse gas reduction policies on the economy as laid down in Rose, Oladosu (2002). This study is chosen as a recent and typical example of impact studies. Rose, Oladosu (2002) analyse the economic consequences for industries and income groups in the US of a marketable permit trading system using a computable general equilibrium model. The environmental target of the simulation experiments is full US Kyoto commitment compared to a baseline scenario until 2010, where carbon emissions rise considerably. The actual reduction of emissions required in 2010 therefore amounts to almost 30 percent and leads to a GDP reduction of more than 1 percent and relatively high permit prices compared to other studies ($ 128 per ton of carbon). Rose, Oladosu (2002) therefore exhibit the economic costs of environmental policy. We tried to introduce the following results of the main scenario of their study in our framework in a consistent way:

Final demand: agriculture: - 1.2%, manufacturing: - 1.5%
Output: agriculture: - 2.5%, manufacturing: - 3.0%
Carbon emissions: - 29.5%
(implicit) Carbon intensity: agriculture: - 27%, manufacturing: - 26.5%

Obviously this is a simplified treatment of the results of Rose, Oladosu (2002) and we are not fully free to change all variables in our framework, where output is determined endogenously for given values in the final demand vector $\frac{F_Q}{F_C}$. Output figures from the Rose, Oladosu (2002) study have just been used to derive the changes in carbon and energy intensity, for which we have coefficients in our framework in the row vectors $\mathbf{c_E}$ and $\mathbf{v_E}$. Essentially what we introduce in our model are simultaneous changes of final demand and carbon as well as energy intensity. For this purpose we also use the results from Rose, Oladosu (2002) for the changes in the input of single fuels (coal, oil, gas), as a considerable part of the cabon emission reduction is due to fuel shifts. Therefore the reduction in energy intensity (relevant for the price model) is much smaller than the reduction in carbon intensity (relevant for the quantity model).

In a satellite system of national accounting we were only able to describe these changes in economic variables accompanied by changes in emissions without having a simultaneous valuation of the two developments. In the EF concept we would measure an 'increase in sustainability' without taking into account the economic losses in terms of output. The EVA concept shall allow us to derive the impact of this greenhouse gas reduction policy on our indicators based on commensurable energy units.

First of all we can solve the system comprising (7), (9) and (10) simultaneously under the restriction $\mathbf{C_E} = \mathbf{C_S}$. This is done by changing the final demand for emission absorption activity within $\mathbf{F_C}$ until the condition is fulfilled. From this solution of the quantity model we can derive the new i-o table (Table 5).

>>>>> Table 5: Input-output quantity model: Greenhouse gas reduction policies

The new i-o table is characterised by the same technology for intermediates (as we also started from the same Leontief inverse) but a different output vector and a different vector of primary inputs.

In a second step we use the new row vector $(v_{EF}\, v_{ES})$ together with the original Leontief inverse to calculate the solution of the price system (equation (11)). This yields the new price vector in 'energy values' (10^3 PJ) for the 'greenhouse gas reduction policy' case:

Agriculture	13.3
Industry	2.2
Autotroph	71.7
Heterotroph	4313.3
Detritus	1929.8

Soil/Ocean 416.3

Emission Absorption 113.6

We observe that prices of economic activity (agriculture, industry/services) in energy values have decreased through less energy and carbon intensity and ecosystem prices have remained the same as before. Again the price solution can be used to transform the i-o table into a table measured in energy values (Table 6).

>>>>> Table 6: Input-output model at prices in energy values: Greenhouse gas reduction policies

There we observe changes in value added as well as final demand. The lower energy intensity of economic activity also leads to a decrease of economic activity measured at 'energy values'. This might be seen as a bias of the valuation concept against energy intensity decreasing policies. If the same emission reduction is reached in one case (i) only by fuel shift and in another case (ii) only by an increase in energy efficiency, then we could possibly observe no change in value added of the economy in (i) and considerable changes in value added of the economy in (ii). This effect must be interpreted as a 'price effect': Increased energy efficiency in the economy has a negative impact on current energy value prices like increased productivity of primary inputs ceteris paribus decreases prices in the static i-o price model. This observation suggests that the analysis should also be carried out in constant prices.

We can compare now the results for all aggregates we derived above (the 'base case') for the case of greenhouse gas reduction policies (Table 7).

>>>>> Table 7: Value added, final demand and ecological value added

The significant change is the decrease of ecological value added, i.e. the value added of emission absorption, from 606 10^3 PJ to 91 10^3 PJ due to the success of greenhouse gas reduction policies. The share of EVA in total value added now amounts to 1.2 percent compared to 7.3 percent before. Relating EVA to the ecosystem value added without economic activity and emission absorption (6739 10^3 PJ) now gives us a share of EVA of 1.3 percent compared to 9 percent before. At the final demand side of the system we get now a share of EVA in total human final demand of 1.7 percent compared to about 11 percent before.

Total final demand (= total net product or value added) at current prices has decreased due to (i) output losses in the economy (volume effect), (ii) increased energy efficiency in the economy (price effect) and (iii) a sharp decrease of ecological value added (value added of emission absorption). As ecological value added decreases much more than the other aggregates, all indicators of the burden of emission absorption improve. This result becomes even more pronounced, if we compare the relation of ecological value added to the value added of economic activity (in energy values).

7. **Conclusions**

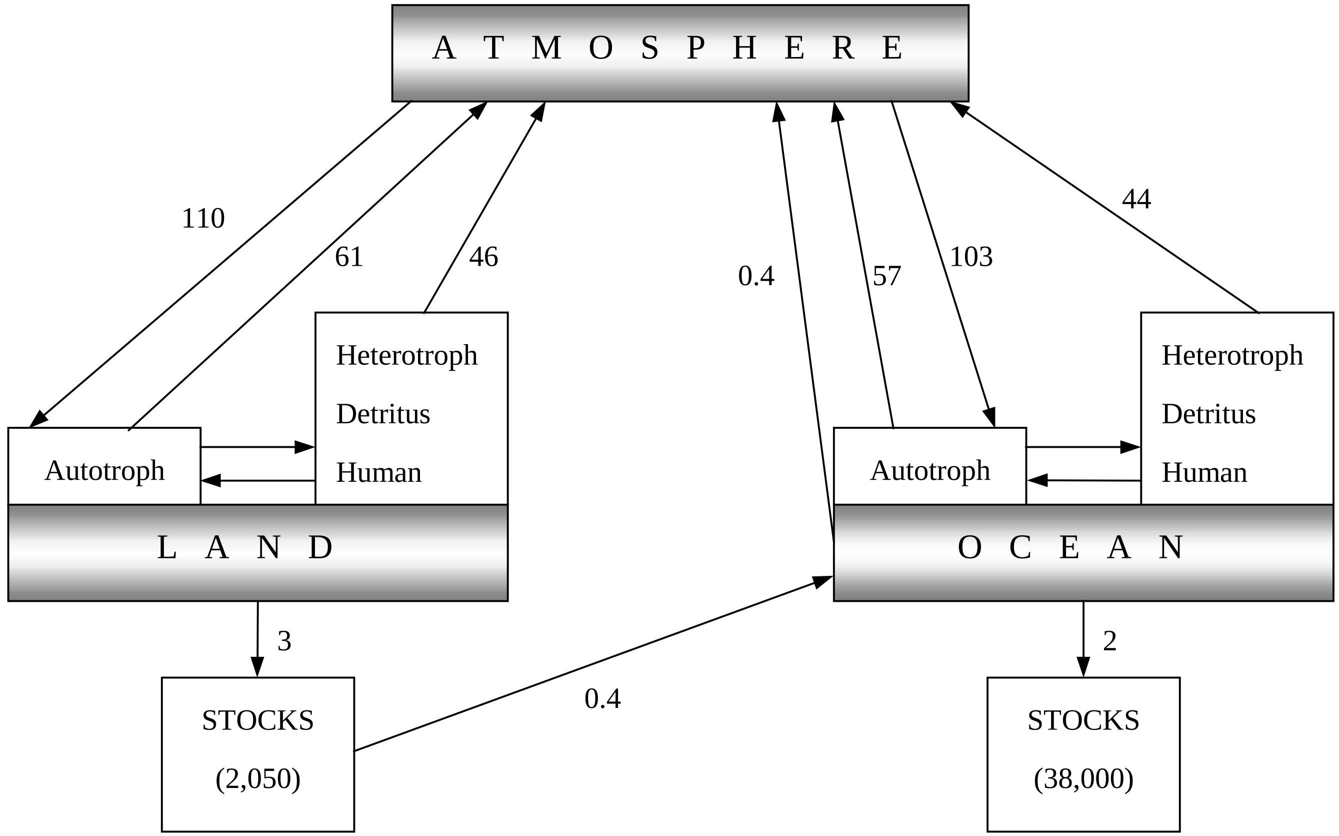
This study describes a synthesis of the concept of ecosystem pricing via 'energy values' in an input – output system with the basic concept of the 'Ecological Footprint' (EF). Actually the study deals only with <u>one</u> environmental problem, namely carbon emissions on a global scale. The framework derived is an integrated economy-ecosystem i-o model , where the EF concept is built in as an additional emission absorption activity like in Leontief´s pollution model (Leontief (1970)). The main result is that this combination of a concept of ecosystem value together with the emission absorption that <u>would have been necessary in the ecosystem for sustainability</u> allows to derive the value of this 'excess emission' beyond carrying capacity. The sustainability target in this context is a balance of carbon flows and sinks, so that atmospheric concentration of carbon would not rise. This target might be inforced by aiming at a lower level of atmospheric concentration of carbon in order to counteract global climate change. The solution of the proposed model indicates the necessary level of emission absorption for any environmental target. Valuation is introduced by using energy as the value added component in the ecosystem, which allows to transform all aggregates into ‘energy values’. The basic innovation of the proposed framework therefore is transforming the idea of EF (ecological footprint) into EVA (ecological value added). The numerical examples show the huge potential of the i-o system and possible extensions of the framework towards a dynamic model.

The simulation results for greenhouse gas reduction policy clearly reveal the comparative advantage of the EVA concept over satellite accounts or the EF concept. The EVA concept allows to measure and directly compare changes in emissions and economic output in a consistent way by using a well defined i-o system with commensurable units.

The potential for applications of the proposed approach might be seen in several fields. First of all satellite accounts in national accounting, e.g. the NAMEA (National Accounting Matrix Including Environmental Accounts), could be extended towards an integrated system including bio-geochemical cycles. Data collection research for the carbon cycle has already begun, for example in Europe. In the end this could lead to the framework proposed in this study including pricing at energy values and deriving the 'ecological value added'.

As the simulation results for policy evaluation have shown, the static accounting framework can be used to derive sustainability indicators in the context of modeling. These sustainability indicators could be integrated into modeling, for example like the 'equivalent variation' concept is integrated in most general equilibrium models as a welfare measure. The existing generation of E3 (economy-energy-environment) models has traditionally put the emphasis on the economic and energy part, whereas carbon emissions mostly represent the 'open end' of the models. This is simply a reflection of the state of environmental accounting, where the satellite accounts represent this 'open end'. Actually one could think of using the approach presented in this study as a starting point for improving the usually less developed environment-economy links in E3 models.

Figure 1: The global carbon cycle



Source: Third Assessment Report, Part 1 (Houghton, et al. (2001)), the figures represent a 'mix' between the figure at p.188 in Houghton, et al. (2001) and different numbers in the text. Agricultural autotroph production and human perturbation are not included.

Table 1: Physical input-output table of the ecosystem: carbon flows (PgC)

	Autotroph	Heterotroph	Detritus	Soil, Ocean	INPUT, Z(j)	FINAL DEMAND		OUTPUT, Q
						Human	Carbon Stock	
INTERMEDIATE CONSUMPTION								
Autotroph		22.6	64.5	2.7	89.8	5.0		94.8
Heterotroph			3.0		3.0	1.0		4.0
Detritus		8.1		1.0	9.1			9.1
Soil, Ocean							5.1	5.1
ENVIRONMENT								
Atmosphere (Sink)	212.6			1.8	214.4			214.4
Atmosphere (Emission)	−117.8	−26.7	−58.4	−0.4	−203.3	−6.0	−5.1	−214.4
PRIMARY INPUT								
Stock (Carbon)	2,051.0			38,000.0				
Stock (Area, 10^6 ha)	13,590.0							
Solar Energy (10^3 PJ)	6,795.0							
OUTPUT	94.8	4.0	9.1	5.1				

Table 2: Physical input-output table of integrated economy-ecosystem model (money units and PgC)

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Soil, Ocean	Emission Absorption	INPUT, Z(j)	FINAL DEMAND Human	FINAL DEMAND Carbon Stock	ECONOMIC OUTPUT, Q	CARBON OUTPUT, C
INTERMEDIATE CONSUMPTION												
Agriculture		20.0						20.0	40.0		60.0	
Industry	35.0	100.0						135.0	120.0		255.0	
Autotroph				22.6	64.5	2.7		89.8	5.0			94.8
Heterotroph					3.0			3.0	1.0			4.0
Detritus				8.1		1.0		9.1				9.1
Soil, Ocean										5.1		5.1
Emission Absorption										5.3		5.3
ENVIRONMENT												
Atmosphere (Sink)	8.2		212.6			1.8	9.7	232.3				232.3
Atmosphere(Emission)	−6.2	−3.7	−117.8	−26.7	−58.4	−0.4	−4.4	−217.6	−9.6	−5.1		−232.3
PRIMARY INPUT												
Stock (Carbon)	169.0		2,051.0				194.0					
Stock (Area, 10^6 ha)	1,350.0		13,590.0				1,212.5					
Solar Energy (10^3 PJ)	675.0		6,795.0				606.3					
Value Added (Money)	100.0	700.0										
Fossil Energy (10^3 PJ)	63.9	110.4										
Total Energy (10^3 PJ)	738.9	110.4	6,795.0				606.3					
OUTPUT, Q/C	60.0	255.0	94.8	4.0	9.1	5.1	5.3					

Table 3: Leontief-inverse of the economy-ecosystem model

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Soil, Ocean	Emission Absorption
Agriculture	1.0814	0.1395					
Industry	1.0378	1.7791					
Autotroph			1.0	60.1769	26.9231	5.8085	
Heterotroph				3.0083	0.9917	0.1945	
Detritus				6.0917	3.0083	0.5899	
Soil, Ocean						1	
Emission Absorption							1.0

Table 4: Input-output table of integrated economy-ecosystem model
(at prices in energy values, 10^3 PJ)

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Soil, Ocean	Emission Absorption	INPUT, Z(j)	FINAL DEMAND Human	FINAL DEMAND Carbon Stock	OUTPUT, Q/C
Agriculture		275.3						275.3	550.7		826.0
Industry	87.1	248.9						336.0	298.6		634.6
Autotroph				1,622.1	4,621.0	193.5		6,436.6	358.4		6,795.0
Heterotroph					12,939.9			12,939.9	4,313.3		17,253.2
Detritus				15,631.2		1,929.8		17,561.0			17,561.0
Soil, Ocean										2,123.3	2,123.3
Emission Absorption										606.3	606.3
TOTAL	87.1	524.2		17,253.2	17,561.0	2,123.3		37,548.8	5,521.0	2,729.6	45,799.3
VALUE ADDED											
Total Energy (10^3 PJ)	738.9	110.4	6,795.0				606.3				
OUTPUT, Q/C	826.0	634.6	6,795.0	17,253.2	17,561.0	2,123.3	606.3				

Table 5: Input-output quantity model: Greenhouse gas reduction policies (money units and PgC)

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Soil, Ocean	Emission Absorption	INPUT, Z(j)	FINAL DEMAND Human	Carbon Stock	OUTPUT, Q/C
INTERMEDIATE CONSUMPTION											
Agriculture		19.7						19.7	39.5		59.2
Industry	34.6	98.5						133.1	118.2		251.3
Autotroph				22.4	64.0	2.7		89.1	4.9		94.0
Heterotroph					3.0			3.0	1.0		4.0
Detritus				8.0		1.0		9.0			9.0
Soil. Ocean										5.1	5.1
Emission Absorption										0.8	0.8
ENVIRONMENT											
Atmosphere (Sink)	8.1		210.8			1.8	1.5	222.2			
Atmosphere(Emission)	–4.5	–2.7	–116.8	–26.5	–57.9	–0.4	–0.7	–209.4	–7.7	–5.1	
PRIMARY INPUT											
Stock (Carbon)	166.8		2,034.1				29.1				
Stock (Area, 10^6 ha)	1,332.7		13,477.9				181.8				
Solar Energy (10^3 PJ)	666.3		6,738.9				90.9				
Value Added (Money)	98.7	689.8									
Fossil Energy (10^3 PJ)	44.3	76.3									
Total Energy (10^3 PJ)	710.6	76.3	6,738.9				90.9				

Table 6: Input-output model: greenhouse gas reduction policies
(at prices in energy values, 10^3 PJ)

	Agriculture	Industry	Autotroph	Heterotroph	Detritus	Soil, Ocean	Emission Absorption	INPUT, Z(j)	FINAL DEMAND		OUTPUT, Q/C
									Human	Carbon Stock	
Agriculture		261.9						261.9	525.2		787.1
Industry	76.5	218.2						294.8	261.8		556.5
Autotroph				1,607.4	4,583.9	193.5		6,384.9	354.1		6,738.9
Heterotroph					12,836.0			12,836.0	4,261.5		17,097.5
Detritus				15,490.1		1,929.8		17,419.9			17,419.9
Soil, Ocean										2,123.3	2,123.3
Emission Absorption										90.9	90.9
TOTAL	76.5	480.2		17,097.5	17,419.9	2,123.3		37,197.4	5,402.6	2,214.2	44,814.2
VALUE ADDED											
Total Energy (10^3 PJ)	710.6	76.3	6,738.9				90.9				
OUTPUT, Q/C	787.1	556.5	6,738.9	17,097.5	17,419.9	2,123.3	90.9				

Table 7: Value added, final demand and 'ecological value added' (at prices in energy values, 10^3 PJ)

	Base case	Greenhouse gas reduction policy
Value added, economy	849.3	786.9
Value added, ecosystem	7,401.3	6,829.8
Value added, emission absorption	606.3	90.9
Value added, total	8,250.6	7,616.7
Emission absorption as percentage of		
total value added	7.3	1.2
ecosystem value added	8.9	1.3
Final demand, human	5,521.0	5,402.6
Final demand, ecosystem	2,729.6	2,214.2
Final demand, emission absorption	606.3	90.9
Final demand, total	8,250.6	7,616.8
Emission absorption as percentage of		
human final demand	11.0	1.7

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