Environmentally Extended Input-Output Analysis of the UK Economy: Key Sector Analysis

The paper assesses sustainability of investment in different economic sectors with the aim of minimizing resource use and generation of emissions. An environmentally extended static 123 sector UK input-output model is used, linking a range of physical flows: domestic extraction, use of water, emissions of CO2, CH4, NOx, with an economic structure of the UK. A range of environmentally adjusted forward and backward linkage coefficients has been developed, with a particular focus on final demand, domestic extraction, publicly supplied and directly abstracted water, CO2 emissions and NOx emissions adjusted coefficients. The data on the final demand- and environmentally adjusted forward and backward linkage coefficients was used in a multicriteria decision aid assessment, employing a NAIADE method in three different sustainability settings. The assessment was set in a way that each sector of the UK economy was assessed using a panel of sustainability criteria, maximizing economic and minimizing environmental effects.

Keywords: input-output analysis, environmentally extended, MCDA, key sectors, sustainability, ecological economics, UK

Introduction

Three key elements seem to be crucial for the socio-ecological transformation if our society is to reach sustainable development and overcome growing energy and resource requirements and rising volumes of emissions and wastes, facilitate the change towards renewable energy sources and conservation of biodiversity. Firstly, this is a the concept of industrial ecology (Graedel & Allenby 2002), which highlights the importance of intersectoral flows of matter and energy required for the production of the goods and services, analysed in detail throughout the whole lifecycle of the given product, service or a whole regional or national system. Secondly, it is the system of tools for decision making (Söderbaum 2000) based on multicriteria methods, which applied at different levels would shift the patterns of decisions making towards more socially equitable and more environmentally friendly as well as economically sound decisions. Thirdly, it is a system of macroeconomic goals or sustainability assessment methods, that dominate on the macroeconomic scene. For a very long time GDP has been the key variable, which was at the heart of macroeconomic policies all over the world. Due to the efforts of ecological economists, and, especially, Herman Daly (Daly 2000) a new vision was proposed, the vision of sustainable development as a qualitative creative change, as opposed to the quantitative growth. The ideas of incommensurability of values, incorporated in the concept of sustainable development have lead to the development of new alternative sustainable development assessment approaches (Stanislav E. Shmelev & Rodríguez-Labajos 2009).

Industrial Ecology. Analysis of Interactions between the Economy and the Environment

The concept of industrial ecology emerged in several places independently, which is . excellently described in two historical overviews of the development of this field (Fischer-Kowalski 1998) and (Fischer-Kowalski & Hattler 1998). The idea of industrial ecology was first proposed by Watanabe in a project, devoted to the study of resource dependency of the Japanese economy (Faye Duchin & E. Hertwich 2003), and a little later Robert Ayres independently developed the principles of this emerging discipline (Ayres R. U. 1978), (Ayres R.U.; Simonis U. 1994), (Ayres R.U.; Ayres L. 2002). The latter has been one of the true pioneers in the field of analysis of economy-environment interactions: a formal mathematical framework for tracing residual flows in the econonomy was offered in (Robert U. Ayres & Kneese 1969), ideas of a stationary state economy were explored in (Robert U. Ayres & Kneese 1971), the ideas on the interaction between economy and the environment resulted in the solid book (Ayres R.U. et al. 1970). These ideas were clearly influenced by the work of Wassily Leontief in the field of input-output analysis of the USA economy (Leontief 1936), (Leontief 1949), (Leontief 1952), see Table 1, and especially by the environmentally extended applications of the input-output analysis to appear in (Leontief 1970), (Leontief 1974) (Leontief 1977a). Leontief built a conceptual link between the structure of the economy and the interdependent economic sectors and the environmental impacts of economic activity, namely CO emissions.

Different countries started to develop input-output tables since the publication of the first balance of the national economy of the USSR and its subsequent criticism by Leontief (Table 1). Tables for USA (1919, 1929, 1947) followed. Later Norway (1948), the Netherlands (1948), Japan (1951) and the UK (1954) joined the process. With a little delay, Hungary (1957), Poland (1957), USSR (1959) and Brazil (1959) continued the trend. The resolution of the input-output tables varied significantly: if the first tables for the USA contained 44 and 41 sectors respectively, the Netherlands – 35 sectors; it was soon realized that increasing the amount of detail allows unprecedented capacity to understand and manage the complexity of intersectoral linkages. Subsequently tables for the USA included 400 sectors, Japan – 399 sectors; Estonia – 239 sectors; Lithuania – 239 sectors; Belorussia (500 sectors).

The first tables to appear in the USSR after the WWII, including the tables for Estonia, Latvia and Lithuania (239 sectors, 1961) have been described in (Jasny 1962) and (Kossov 1964). The first Dutch input-output tables to appear have been reviewed by (Rey & Tilanus 1963), the first international comparative analysis of the economies of the USA, Japan, Norway, Italy, Spain using input-output tables was offered by (Simpson & Tsukui 1965).

The environmentally extended input-output applications started to develop in the 1970s following the original publication by Leontief and covered the following issues: energy and the environment (Carter 1974), (Carter 1976), (Herendeen & Tanaka 1976), (J. L. R. Proops 1977), (Park 1982), (Proops 1984), (Gay & John L. R. Proops 1993), (Polenske & Lin 1993); materials balance and materials flows (F. Duchin 2004), (Giljum 2004), (Hoekstra R. 2005), (Tukker et al. 2009), (Suh S. (Ed) 2009); water (Anderson & Manning 1983), (Lenzen M. & Foran B. 2001), (L. Wang et al. 2005), (Dietzenbacher & Velázquez 2007), (Lenzen 2009), (H. Wang & Y. Wang 2009); waste (Leontief 1977b), (Faye Duchin 1990), (Faye Duchin 1994), (Nakamura 1999), (Nakamura & Kondo 2002), (Kondo & Nakamura 2005), (Nakamura & Kondo 2006) and the environmental policy analysis (Gutmanis 1975). The UN global model project has significantly stimulated interest to the analysis of the environmental consequences of economic development and effects of technological innovation (Leontief 1977), (R.U. Ayres & Shapanka 1976), (Petri 1977), (Carter & Petri 1979) (Leontief & Faye Duchin 1986). Substantial projects focused on the application of input-output analysis to national economies for policy analysis have been started in various countries including the UK (Barker et al. 1980), (Barker 1981), (Stone 1984). Dynamic input-output analysis has become one of the most interesting subjects of economic research (Vogt et al. 1975), (F. Duchin & Szyld 1985), (Raa 1986). Environmentally extended input-output analysis of the changes in the world economy has been carried out by (Leontief & Faye Duchin 1986), (Faye Duchin 1986), (Fontela 1989), (Schäfer & Stahmer 1989),. Later, this framework was extended to include material flows (Duchin, 2004), other pollutants (Faye Duchin 1994), (Faye Duchin 1998) and different types of waste (Nakamura, 1999). The most recent applications of extended input-output analysis today include an environmental key sector analysis by Manfred Lenzen (Lenzen, 2001), and econometric extended-input-output models of the UK and the European Union (Barker, Ekins et al. 2007), (Barker, Junankar et al. 2007).

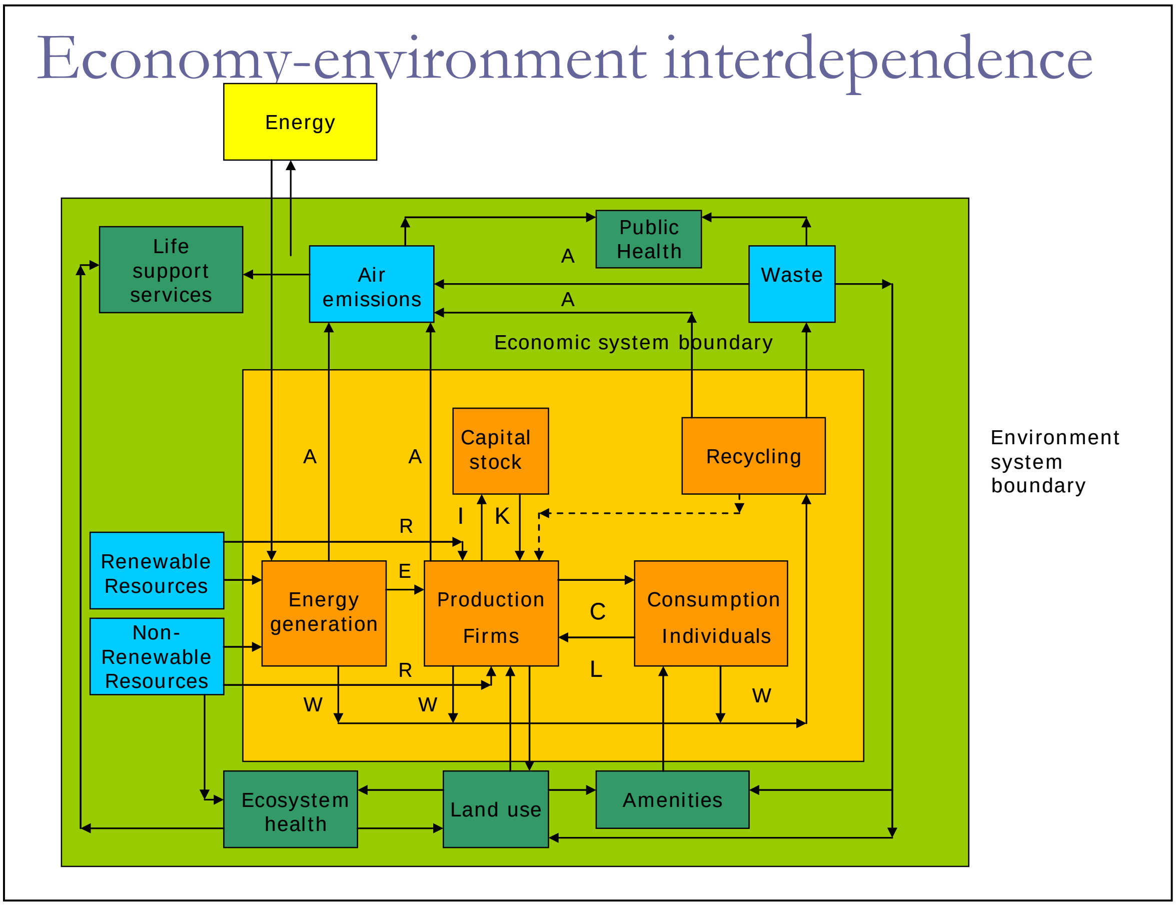


Figure 1. Economy-Environment Interdependence

Figure 1 contains schematic description of material and energy flows in the national economy. The outer light green box depicts the boundaries of the environment system, with a yellow box "Energy", responsible for the transfer of solar energy to ecosystems and humans. The inner dark yellow box represents the economic system, forming the part of a wider environmental system, and constrained by the limitation of the environmental system. The principle of embeddedness of the economic system into the environmental system became the subject of considerable debate and a lot of attention from such pioneers of ecological economics as Herman Daly ((Daly 2000)). The dark ochre boxes represent fundamental economic activities, such as energy generation, production, consumption, accumulation of capital stock and recycling, a new type of economic activity, designed to bring economic systems closer to the sustainable path and emulate the natural ecological metabolic processes. Light blue boxes in the chart represent the stocks of renewable and non-renewable resources taken from the natural environment and emissions and waste emitted to the environment as a result of the functioning of the economic system. Emissions to water and some other factors are not considered here for the sake of simplicity. The dark green boxes situated outside of the economic system represent the key factors that should be taken in the account, when analyzing the future development of the economy: life support services, ecosystem services, public health, visual and other amenities, and land use generally. It is a very rough classification of the types of impacts that could be adjusted in each individual case. It was successfully applied to the analysis of the sustainability of the regional waste management systems (S.E. Shmelev & Powell 2006). When such a range of aspects of the development of a given regional or a national system is considered, it seems desirable to use special multicriteria methods to support decisions at all levels of the decision making process, which will be covered in the next section of the paper.

Table 1. Input-Output Tables Published in World Countries

Country	Year, Referring To	Number of Sectors
USSR	1923/24	12 sectors
USA	1919	44 sectors
USA	1929	41 sector
USA	1947, 1958, 1963	400 sectors, 480 intermediate sectors
Norway	1948	175 sectors
Netherlands	1948-1957	35 sectors
Japan	1951, 1973, 1976	399 intermediate sectors (2005)
UK	1954, 1961	123 intermediate sectors
Hungary	1957	40 sectors
Poland	1957	20 sectors
USSR	1959	83 sectors
Brazil	1959	32 sectors
Brazil	1969, 1970	87 sectors
Estonia	1961	239 sectors
Lithuania	1961	239 sectors
Canada	1961	250 industries
Belorussia	1962	500 sectors

China	1973	61 sector,
China	1997	124 commodities
Australia	1974	135 sectors
OECD	1972, 1977, 1982	48 sectors

In his pioneering article Lenzen (Lenzen 2003) introduced the concept of environmentally important paths, linkages and key sectors in the macroeconomic framework. Historically Rasmussen was the first one to introduce the concept of forward and backward inter-industry linkages as measures of structural interdependence (Rasmussen 1956), (Hirschman 1958), (Hewings et al. 1989), (Sonis et al. 1995), and (Sonis & Hewings 1999). Lenzen (Lenzen, 2003) for the first time introduced the idea of an environmentally adjusted forward and backward inter-industry linkages. In this paper such an approach is taken one step further and applied to the environmentally extended input-output model of the UK economy, comprising 123 sectors and additional flows of domestically extracted materials, directly abstracted and publicly supplied water and emissions of CO_2, NH_4, NO_x. Environmentally adjusted forward and backward oriented linkages are calculated here for all the 6 mentioned environmental aggregates and illustrate the pattern of direct and indirect effects of investing in particular sector of the UK economy as of 2000

The particular innovative aspect of this paper is the subsequent treatment of the derived forward and backward linkage coefficients with the help of multicriteria decision aid (MCDA) tools, which helps to identify the most "sustainable" sectors of the British economy in terms of their power to stimulate economic development, producing at the same time the minimal environmental effects across the national economy.

Table 2. Major contributions in environmentally extended input-output analysis

Author, year	Country of application	Sectoral Dimensions	Extensions
(Leontief 1970)	N/A	2x2	1 pollutant, agriculture and manufacturing
(Leontief & Ford 1972)	USA	90 sectors	5 residuals, 1 recipient (air), 11 final demand categories,
(Leontief 1974)	World		45 sectors, 40 minerals and fuels, 30 pollutants
(Forsund & Strom 1976)	Norway	86 sectors	35 types of residuals, 28 final demand categories
(J. L. R. Proops 1977)	UK	3x3	energy intensities
(Barker 1981)	UK	40 sectors,	econometrics, annual time series 1954-1979, and cross-section data in the form of input-output tables 1954, 1963, 1968, 1974.
(Luptáčik & Böhm 1994)	N/A		MCDA, trade-off between economic goals and the

			quality of the environment
(Kananen et al. 1990)	Finland	17 sectors	MCDA, emergency management
(F. Duchin 1992)	N/A	4x4	industrial ecology
(Gay & John L. R. Proops 1993)	UK	38 sectors	CO_2
(Sonis & Hewings 1998)	Indonesia	5 sectors	structural path analysis, SAM
(Nakamura 1999)	Netherlands	20 sectors	waste, recycling and CO_2 emissions
(Ferrer & Robert U. Ayres 2000)	France	30	waste, remanufacturing
(Moffatt I. & Hanley N. 2001)	Scotland	28 sectors	12 pollution types
(Hoekstra & van den Bergh 2002)	N/A	N/A	MFA and structural decomposition analysis
(Aroche-Reyes 2003)	Mexico	27 sectors	qualitative analysis of economic structures
(Lenzen 2003)	Australia	134 sectors	environmentally adjusted linkage coefficients
(Giljum & Hubacek 2004)	Germany	3x3	primary material inputs
(Lantner & Carluer 2004)	France	36x36	spatial dominance: 6 regions, 6 sectors each
(Suh 2005b)	N/A		MFA and energy
(Suh 2005a)	USA	500 sectors	life cycle input-output
(Peters & Edgar G. Hertwich 2006)	Norway	49 sectors	internatonal trade, embodied CO_2
(Cardenete & Sancho 2006)	Spain, 1995	10 sectors	SAM
(Tarancon Moran & del Rio Gonzalez 2007)	Spain	44 sectors	CO_2 emissions

Integration of the economic input-output analysis and the information on the physical flows going through the economy allows us to undertake a detailed analysis of the structural physical links in the economy with the help of the environmental key sector analysis. Taking into account physical flows is a major advantage of this approach as it allows to look beyond simple monetary value of transactions in the input-output table and explore the rich complexity of physical linkages that exist in the economy. This will prove extremely beneficial in analyzing the economy wide environmental effects of the government investment programmes in the time of crisis. Figures 3 and 4 depict domestic extraction and CO_2 adjusted coefficients of forward and backward linkages, which characterize the national economy of the United Kingdom in 2002 from the point of view of environmental intensities of the physical links among different sectors. All sectors are grouped into four clusters (Figure 3): key sectors, backward linkage oriented, forward linkage oriented, and weak oriented sectors.

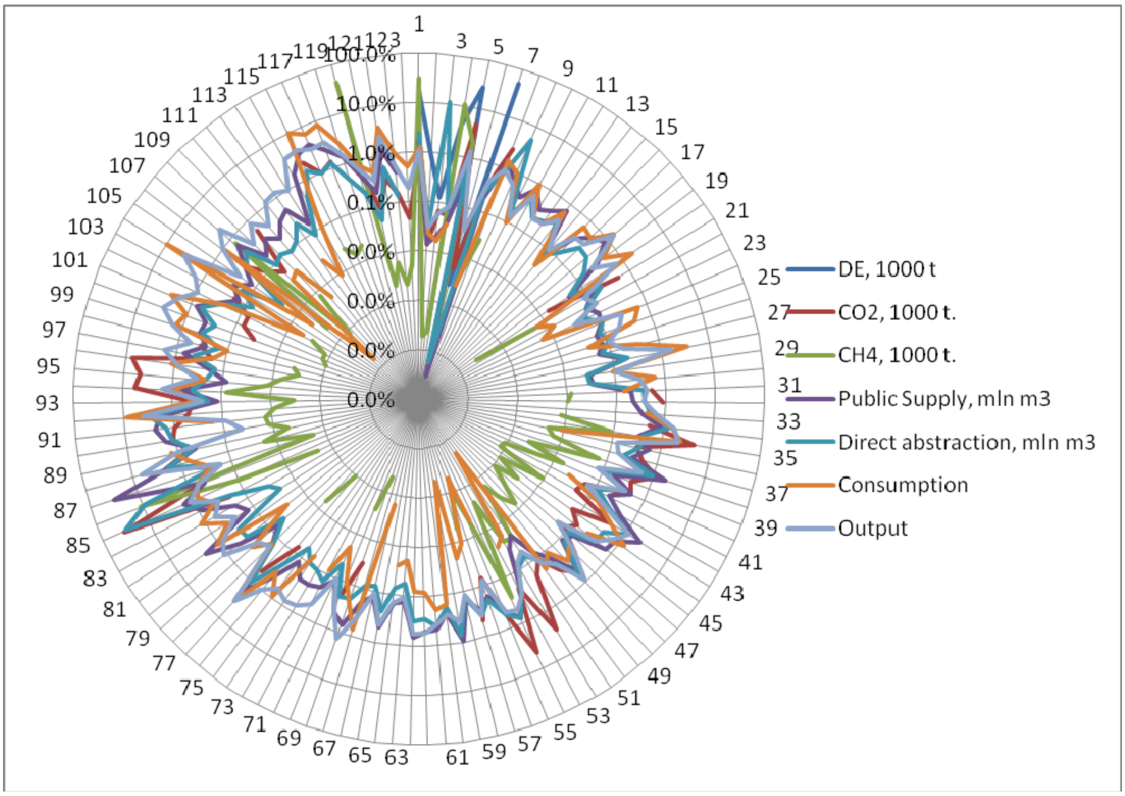


Figure 2. Economic and physical flows in the UK economy (123 sectors), 2002.

Integration of the economic input-output analysis and the information on the physical flows going through the economy allows us to undertake a detailed analysis of the structural physical links in the economy with the help of the environmental key sector analysis. An integrated illustration of the economic and environmental flows in the UK economy is depicted in Figure 2. Each economic sector (the names and respective numbers could be found in Annex 2) is characterized by the share of its domestic extraction of natural resources, publicly supplied and directly abstracted water, emissions of CO_2, CH_4, consumption and economic output, presented on the logarithmic scale. Table 2 presents the most relevant sectors (with shares greater than 5%) in terms of their environmental and economic direct effects with respective percentages of the total flow.

Table 3. Direct environmental and economic sectoral impacts

Dimension	Sectors	Share
Domestic Extraction		
	Other mining and quarrying	49.6%
	Oil and gas extraction	28.0%
	Agriculture	17.2%
Water publicly supplied		
	Water supply	32.4%
Water directly abstracted		

	Electricity production and distribution	33.0%
	Fishing	10.8%
	Gas distribution	9.0%
	Fish and fruit processing	5.1%
CO_2		
	Electricity production and distribution	36.0%
	Air transport	7.6%
	Other land transport	6.0%
CH_4		
	Sewage and sanitary services	42.5%
	Agriculture	31.5%
	Gas distribution	11.3%
	Coal extraction	10.9%
Consumption		
	Letting of dwellings	9.9%
	Public administration and defence	9.8%
	Hotels, catering, pubs, etc	8.8%
	Health and veterinary services	8.1%
Output		
	Construction	6.7%

Figures 3 and 4 depict final demand and CO_2 adjusted coefficients of forward and backward linkages, which characterize the national economy of the United Kingdom in 2002 from the point of view of economic and environmental intensities of the physical links among different sectors. In Figure 3 all sectors are grouped into four clusters: key sectors, backward linkage oriented, forward linkage oriented, and weak oriented sectors. For key sectors the respected value of both forward and backward linkage coefficient is greater than 1.

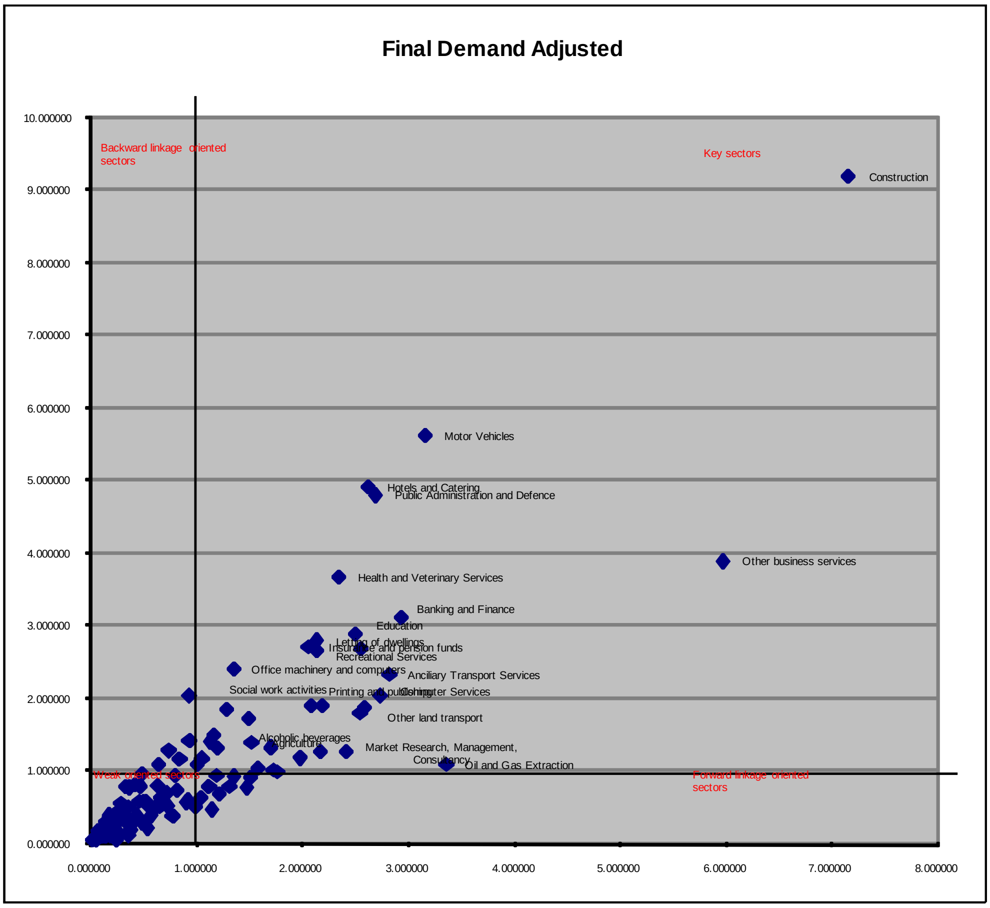


Figure 3 Final Demand Adjusted Forward and Backward linkage coefficients, UK, 2002

We can see from Figure 3, that in pure economic sense, which corresponds to the traditional economic thinking historically applied in different countries, the sectors associated with the strongest economic links with the rest of the economy, capable of stimulating economic development, in the UK in 2002 were construction, other business services, motor vehickles, hotels and catering, public administration and defence, health and veterinary services, banking and finance.

CO_2 adjusted forward and backward linkage coefficients for the major industries depicted in Figure 3, give us a different picture. The most CO_2 forward and backward linked sector is Electricity production and distribution, other key sectors in relation to CO_2 impacts in the UK economy are Construction, Coke ovens, Refined petroleum and nuclear fuel, Motor vehicles, Iron and Steel, Air Transport, Oil and Gas Extraction and several others. It is quite natural, that the forward linkage coefficient for the Oil and Gas Extraction is much higher than the backward linkage since the role, that oil and gas play as fuels in the transport and other sectors. The reverse applies to air transport, due to the amount of fuel that is used on the flights.

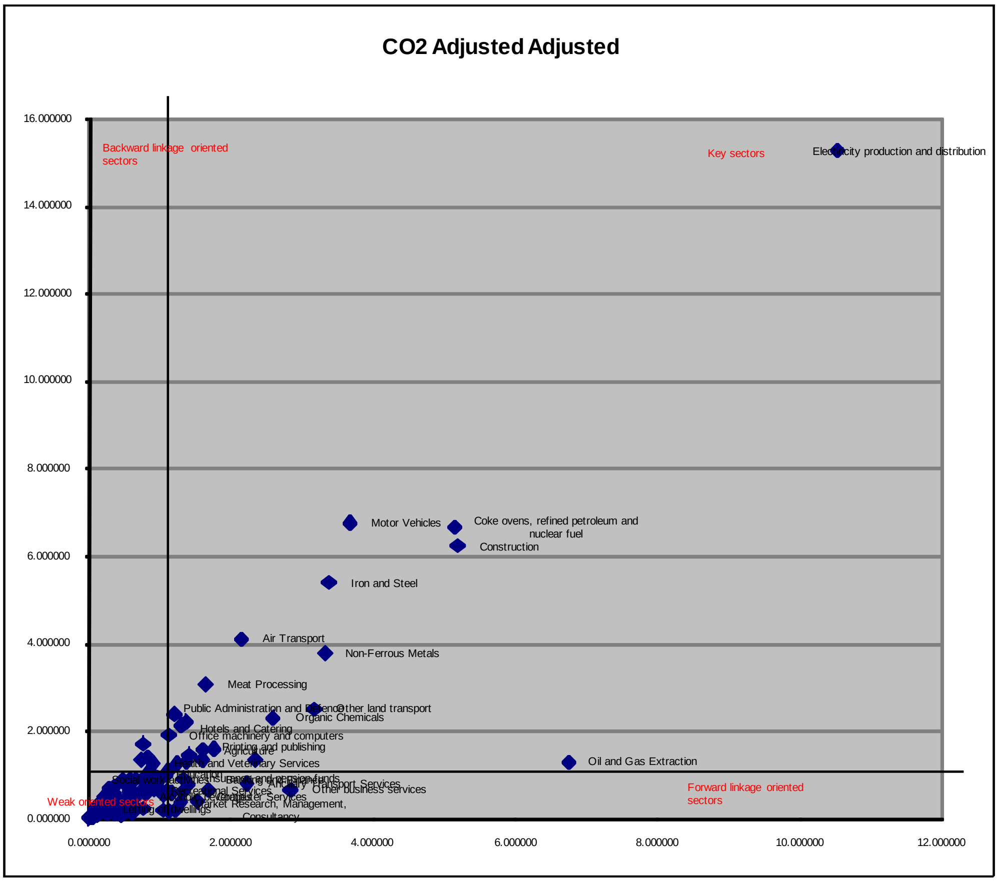


Figure 4. CO2 adjusted forward and backward linkage coefficients, UK, 2002

Key sectors in the environmental sense, when domestic extraction is taken as a basis for weighting the coefficients (Figure 4), were the following: Other mining and quarrying, Construction, Coke ovens, refined petroleum and nuclear fuel, Oil and Gas Extraction, Agriculture, Electricity production and distribution and some others. For these sectors, additional economic activity would mean higher than proportional resource extraction impacts further up and down the supply chain, the respected coefficients are shown on the chart's axis. For example, for an Oil and Gas Sector, domestic extraction adjusted forward linkage coefficient is 9,53 and backward linkage coefficient is 5,16. This means that oil and gas extraction generates forward oriented extraction impacts that are 9.53 times higher than the oil and gas extraction's own domestic extraction impact. Respected interpretation can be applied to the backward linkage coefficients.

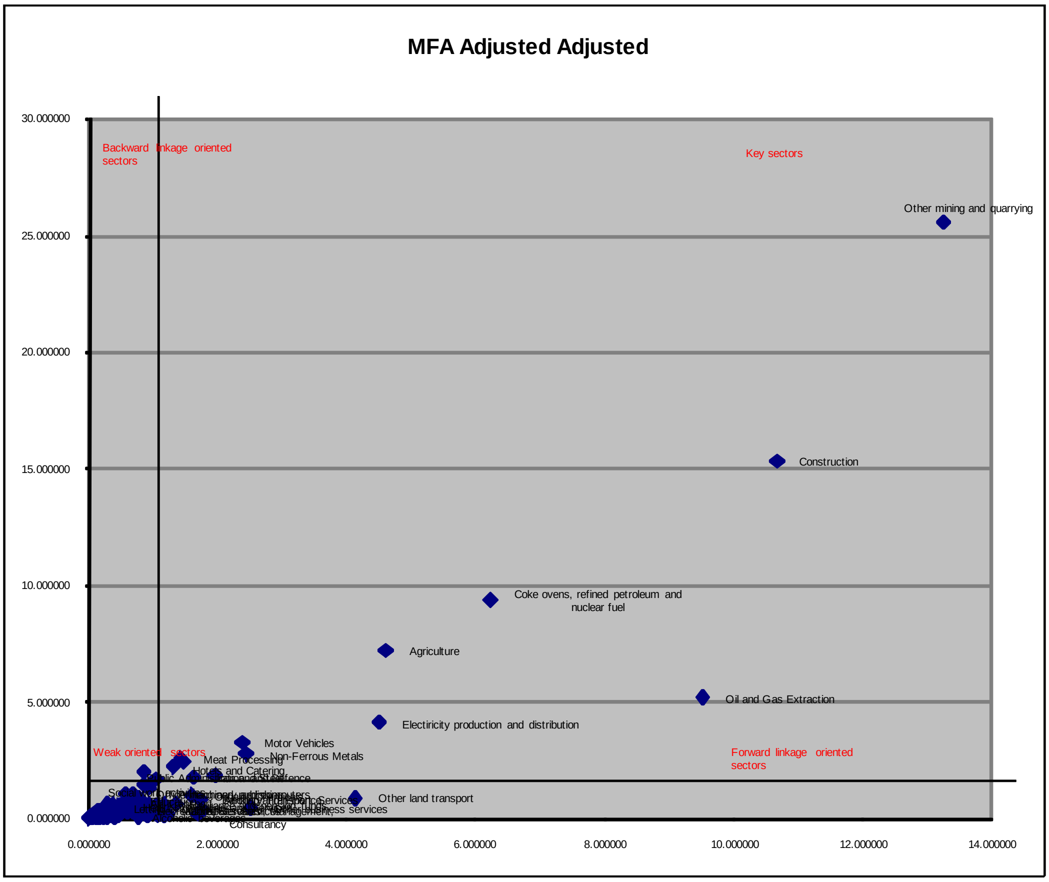


Figure 5. DE adjusted forward and backward linkage coefficients, UK, 2002

When the economic system is considered from the point of view of associated emissions of NO_x (Figure 5), the following pattern is produced. The sector, characterised by the largest potential to influence the generation of NOx emissions in the UK in 2002 was Water Transport, followed by Computer Services, Electricity Production and Distribution, Construction, Motor Vehicles, Non-Ferrous Metals, Coke Ovens etc, Other Land Transport and some others.

When the economic system is considered from the point of view of associated water flows (directly abstracted and publicly supplied) the following pattern emerges. In the case of publicly supplied water the strongest key sectors are: Water Supply, Motor Vehicles, Organic Chemicals, Construction etc. For directly abstracted water the “key sectors” are: Electriciy Production and Destribution, Fish and Fruit Processing, Fishing and so on. (Figures 6 and 7).

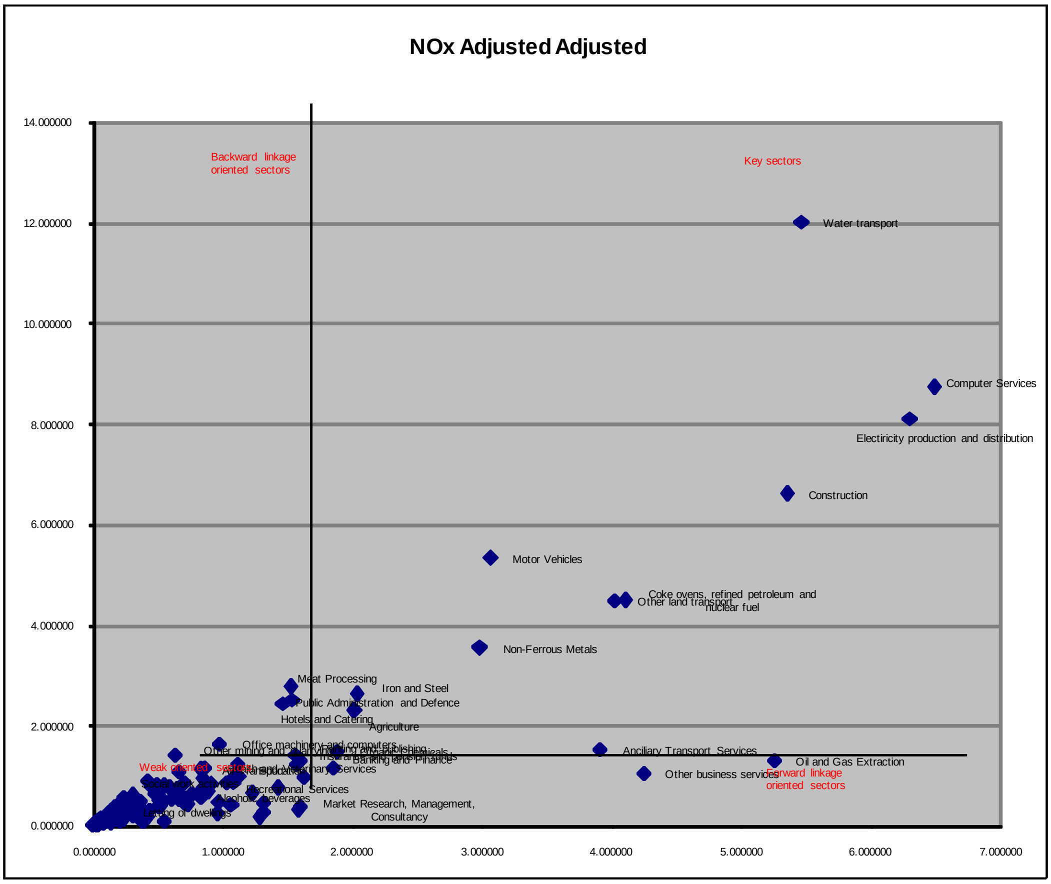


Figure 6. NO_x adjusted forward and backward linkage coefficients, UK, 2002

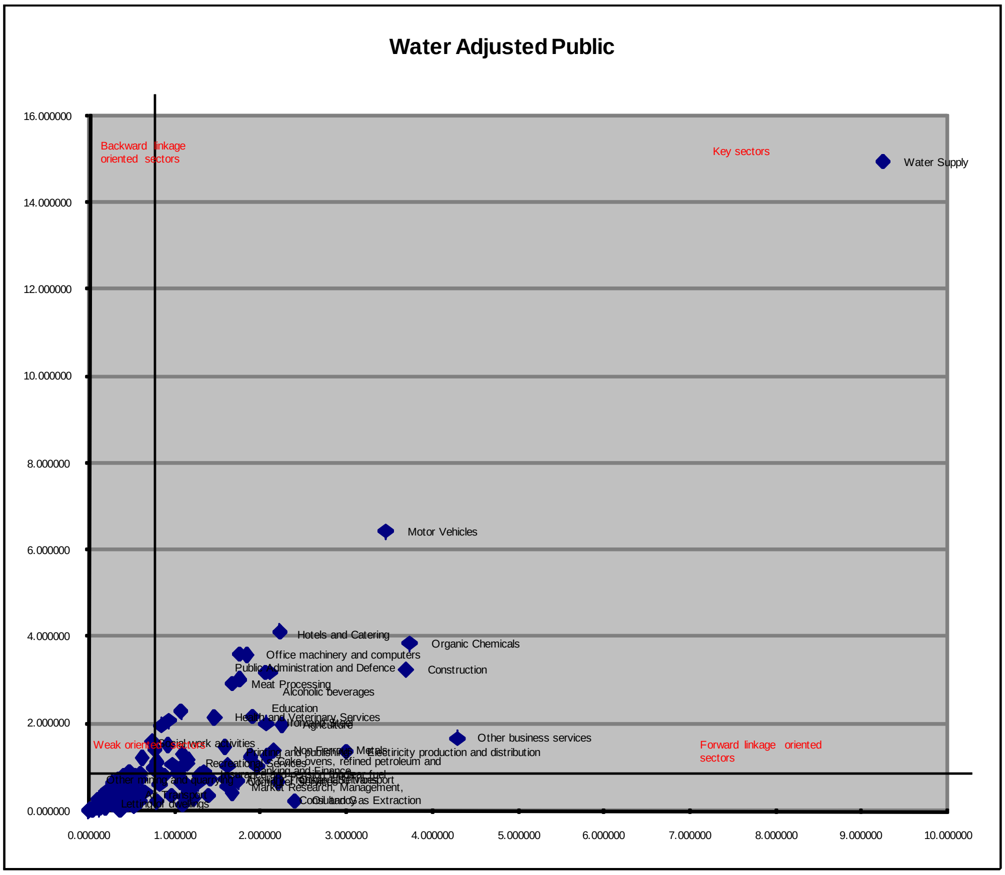


Figure 7. Water adjusted public forward and backward linkage coefficients, UK, 2002

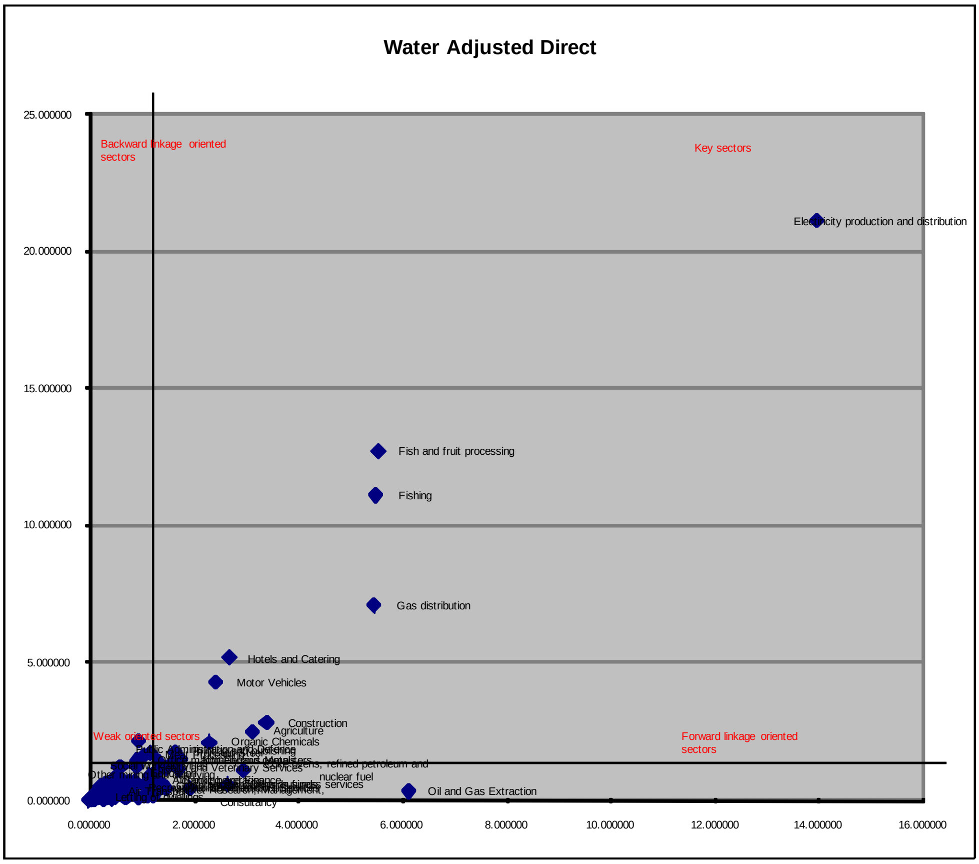


Figure 8. Directly abstracted water adjusted forward and backward linkage coefficients, UK, 2002

Macro Sustainability Assessment

There is a wide spectrum of aspects that should be taken into account when discussing sustainability: the UN system of indicators of sustainability comprises 96 indicators with a core of 50 indicators divided into 14 themes: Poverty, Governance, Health, Education and Demographics, Natural Hazards, Atmosphere, Land, Oceans, Seas and Coasts, Freshwater, Biodiversity, Economic Development, Global Economic Partnership, and Consumption and Production Patterns. Therefore a whole new class of methods is required to address sustainability problems at the local, regional and national level, taking a range of criteria into account simultaneously. Such methods are usually referred to as multicriteria decision aid (MCDA) methods and have been developed within many different schools: in France, in the Netherlands, in the USA, in Russia and several other countries. Methodological work in this field has been done by (Ferrer & Robert U. Ayres 2000) applying these methods to the regional problems, (Roy 1985), the author of one of the most famous families of multicriteria methods, outranking methods “ELECTRE”; (Janssen 1993), who developed a decision support tool called DEFINITE, the author of the method, called NAIADE, based on fuzzy logic. There is an extensive body of work covering the use of multicriteria methods in decision making. A range of multicriteria programming methods has been developed to deal with well structured and quantitatively described problems. Numerous applications of MCE exist for regional problems, e.g.

waste management (S.E. Shmelev & Powell 2006) or renewable energy (Madlener & Stagl 2005). The novel application of such methods to macro sustainability assessment has been offered in (Stanislav E. Shmelev & Rodríguez-Labajos 2009).

Multicriteria Methods

The perspective of the MCDA presents a new paradigm, which is different from the classical goal of finding an optimal solution subject to a set of constraints characteristic of operations research.

NAIADE Method

Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) is a discrete muilticriteria method whose impact (or evaluation) matrix may include either crisp, stochastic or fuzzy measurements of the performance of alternative an with respect to a judgement criterion (Munda 1995), (Munda 2005). No traditional weighting of criteria is used in this method. The whole procedure can be divided in three main steps:
pairwise comparison of alternatives;
aggregation of all criteria;

1) evaluation of alternatives.

The method is based on the concept of the fuzzy preference relation. If A is assumed to be a finite set of N alternatives, a fuzzy preference relation is an element of the NxN matrix $R=(r_{ij})$, i.e.:

$r_{ij}=\mu R(a_i, a_j)$ with $i,j= 1,2,\ldots,N$ and $0<=r_{ij}<=1$

$r_{ij}=1$ indicates the maximum degree of preference of a_i over a_j; each value of r_{ij} in the open interval (0.5, 1) indicates a definite preference of a_i to a_j (a higher value means stronger intensity); $r_{ij}=0.5$ indicates the indifference between a_i and a_j.

Six different fuzzy relations are simultaneously considered:

1) much greater than (>>)
2) greater than (>)
3) approximately eaual to (~)
4) exactly equal to (=)
5) less than (<)
6) much less than (<<).

Given the information on the pairwise performance of the alternatives according to each single criterion, these evaluations are aggregated in order to take all criteria into account simultaneously. As a final result, the method creates the webs of domination relationships among alternatives, and presents them in a useful graphical form. The main distinct feature of NAIADE, which was particular important for our analysis was the capacity to change the degree of sustainability (parameter α), from weak to strong to simulate the changes in perspective on the degree of compensation allowed among the criteria. For more detailed description of the NAIADE method an interested reader is referred to (Munda 1995).

3 Application

The only known application of the MCDA tools in the input-output context belongs to (Luptáčik & Böhm 1994). The authors use input-output model as a basis for the multicriteria optimization programme to identify the optimal structure of output, which minimizes environmental effects under the constraints of primary input. Our approach is different in that working with the real input-output model of the UK economy we use the environmentally adjusted forward and backward linkage coefficients to find the most environmentally sustainable and economically viable industries. The data obtained as a result of the calculation of forward and backward linkage coefficients has been used in the multicriteria decision aid (MCDA) system NAIADE, which is an outranking MCDA tool, capable of handling various types of data including interval, crisp, stochastic and fuzzy elements. The method produces webs of domination relationships, which can be seen in the Annex 1 for the weak, neutral and strong sustainability setting. Table 2 presents the summary of the results in terms of the top sustainable sectors in all the settings.

Table 4. Top sustainable sectors in the UK economy under different assumptions, 2002

Scenario	Top 10 sectors
A=0.1 (weak sustainability)	**104 Letting of Dwellings** **121 Recreational Services** **118 Social Work Activities** **116 Education** **102 Auxilary Financial Services**
A=0.5 (neutrality)	**104 Letting of Dwellings** **117 Health and Veterinary Services** **116 Education** **121 Recreational Services** **118 Social Work Activities**
A=0.9 (strong sustainability)	**115 Public Administration and Defence** **92 Hotels, catering, pubs, etc.** **117 Health and Veterinary Services** **104 Letting of Dwellings** **118 Social Work Activities**

For discussion about the differences between the strong and the weak sustainability in the NAIDE applications the reader is referred to (Stanislav E. Shmelev & Rodríguez-Labajos 2009), the key difference being the ease of compensation among the sustainability criteria in the case of weak and the strong complementarity and not so much compensation in the strong sustainability setting.
The webs of domination relationships among sectors found in the annex position the sectors in relation to their performance on the criteria identified in this paper. The

existence of the arrow between the two sectors denotes the existence of the domination relationship, the lack of such an arrow points to incomparability.
It can be seen that such sectors as 116 (Education), 117 (Health and Veterinary Services), 118 (Social Work Activities), 104 (Letting of Dwellings), 121 (Recreational Services) feature prominently almost in all sustainability settings, and are those sectors that truly provide the basis for the sustainable development of the United Kingdom both in the sense of direct effects and indirect effects, thereby not inflicting the heavy resource use or pollution load across the whole spectrum of economic sectors. This result is extremely important for the preparation of the economic recovery programmes by the UK Government, focused in the neo-Keynesian sense on stimulating the economic recovery. One should hope that this economic crisis will be seen as an opportunity to not only concentrate on the pure economic recovery, but also the wider resource use and environmental impacts and the strategic environmental modernisation of the economy. In any case any reduction in educational or health care budgets according to these results is completely unjustified and would be harmful for the economy in the long run, especially if one takes the sustainability perspective.

Discussion

As our application shows, combination of various approaches proves to be especially fruitful. In our case, environmentally extended input-output analysis has been combined with multi-criteria decision aid to identify the sectors, that are "most sustainable" both in terms of direct and indirect impacts. The unique aspect of this application is in its use of environmentally adjusted forward and backward linkage coefficients that show the effects that are being produced through the web of intersectoral linkages. The paper presented a novel way of assessing relative sustainability of investment in particular economic sectors from the point of view of resource use and generation of emissions. The research carried out can be disaggregated into the following three steps: an environmentally extended static 123 sector UK input-output model has been created, which linked a range of physical flows: domestic extraction, use of water, emissions of CO_2, CH_4, NO_x, with an economic structure of the UK. Secondly, following a range of environmentally adjusted forward and backward linkage coefficients has been developed, with a particular focus on final demand, domestic extraction, publicly supplied and directly abstracted water, CO_2 emissions and NO_x emissions adjusted coefficients. Then the data on the final demand and environmentally adjusted forward and backward linkage coefficients was used in a multicriteria decision aid (MCDA) assessment, employing a Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) method in three different sustainability settings: weak sustainability, strong sustainability and a neutral setting. The assessment was set in such a way that each of the 123 sectors of the UK economy was compared with each other using a panel of sustainability criteria, with final demand adjusted coefficients aimed at their maximum and environmentally adjusted – at their minimum values.

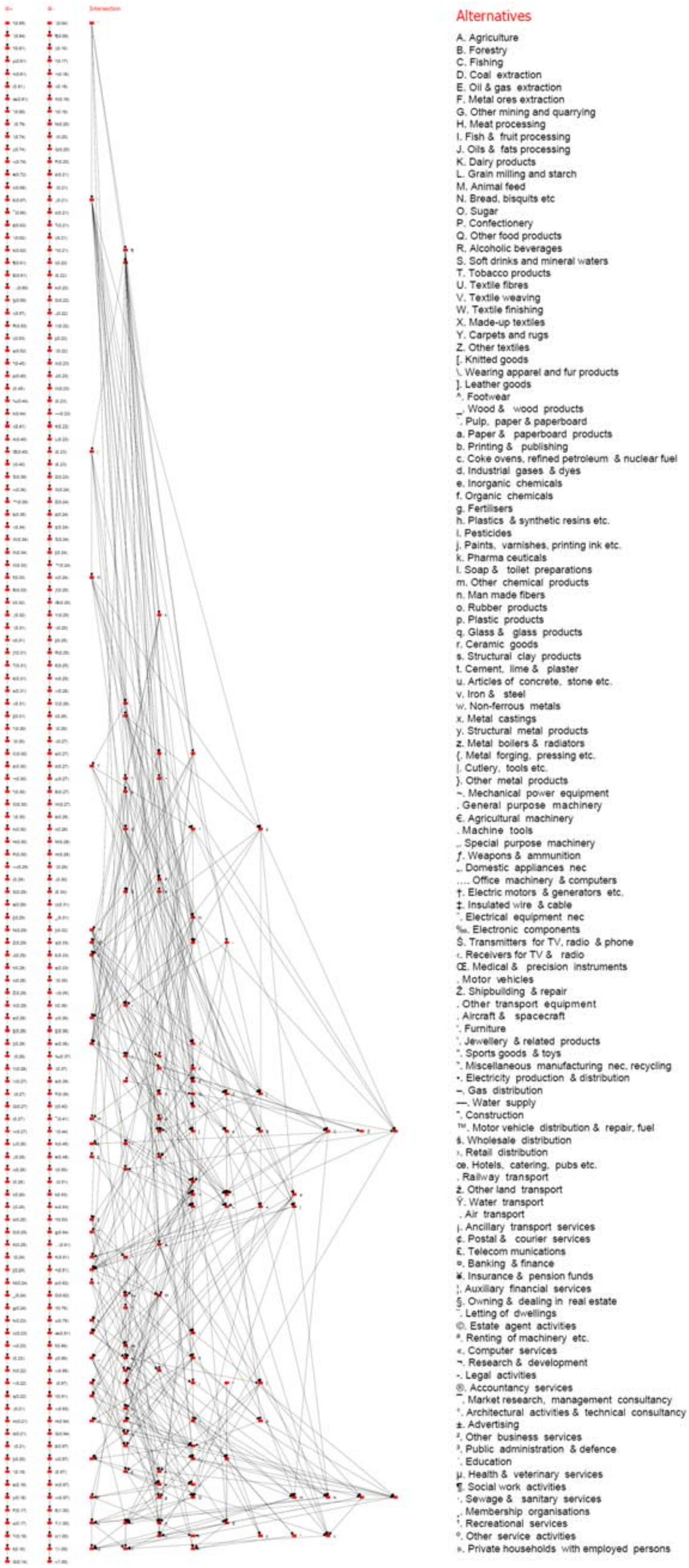
The results show that the following sectors:
117 Health and Veterinary Services
104 Letting of Dwellings
116 Education

121 Recreational Services
101 Insurance and Pension Funds
118 Social Work Activities
99 Telecommunications
with relative stability appear within the top 10 most sustainable sectors of the UK economy from the point of view of both direct and indirect effects in the strong sustainability, weak sustainability and the neutral assessment.

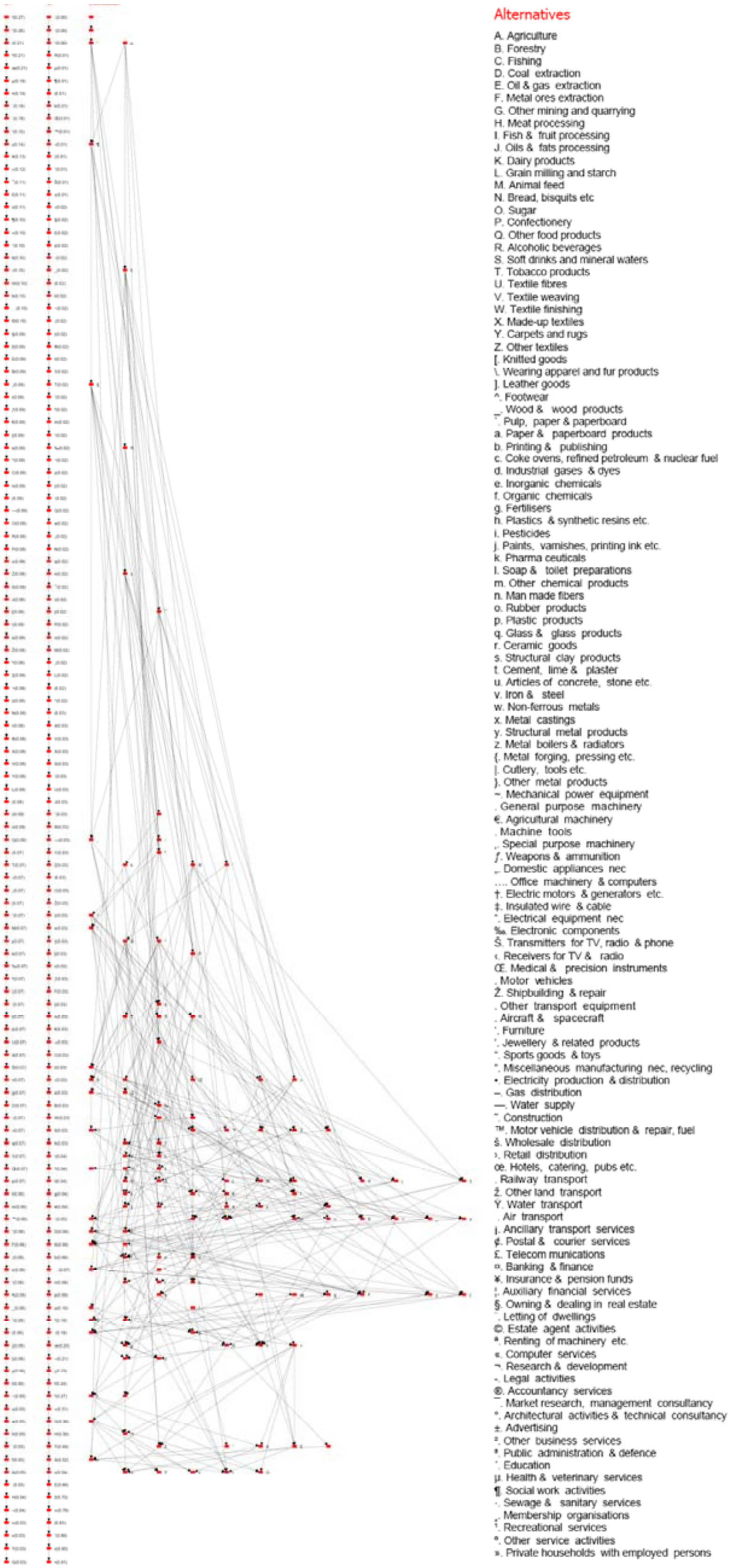
Conclusions

The paper offers a justification for a substantial governmental investment programme, that not only could stimulate the development of the economy, but also reduce the direct and indirect environmental consequences of such a development. Such a programme seems to be particularly desirable in the conditions of the current economic crisis, which on our opinion presents a challenge and at the same time offers an opportunity for reorientation of the governmental investment priorities towards more sustainable industries. Unfortunately this particular aspect of the problem is not currently being discussed by any of the political parties in the UK in the vicinity of the forthcoming election.

Annex 1. α=0.1 - weak sustainability setting



Annex 1. α=0.5 - neutrality setting



Annex 1. α=0.9 - strong sustainability setting

Annex 2. Nomenclature of economic sectors, input-output formulation, Office for National Statistics, UK, 2002

1	Agriculture
2	Forestry
3	Fishing
4	Coal extraction
5	Oil & gas extraction
6	Metal ores extraction
7	Other mining & quarrying
8	Meat processing
9	Fish & fruit processing
10	Oils & fats
11	Dairy products
12	Grain milling & starch
13	Animal feed
14	Bread, biscuits etc.
15	Sugar
16	Confectionery
17	Other food products
18	Alcoholic beverages
19	Soft drinks & mineral waters
20	Tobacco products
21	Textile fibres
22	Textile weaving
23	Textile finishing
24	Made-up textiles
25	Carpets & rugs
26	Other textiles
27	Knitted goods
28	Wearing apparel & fur products
29	Leather goods
30	Footwear
31	Wood & wood products
32	Pulp, paper & paperboard
33	Paper & paperboard products
34	Printing & publishing
35	Coke ovens, refined petroleum & nuclear fuel
36	Industrial gases & dyes
37	Inorganic chemicals
38	Organic chemicals
39	Fertilisers
40	Plastics & synthetic resins etc.
41	Pesticides
42	Paints, varnishes, printing ink etc.
43	Pharmaceuticals

44 Soap & toilet preparations
45 Other chemical products
46 Man-made fibres
47 Rubber products
48 Plastic products
49 Glass & glass products
50 Ceramic goods
51 Structural clay products
52 Cement, lime & plaster
53 Articles of concrete, stone etc.
54 Iron & steel
55 Non-ferrous metals
56 Metal castings
57 Structural metal products
58 Metal boilers & radiators
59 Metal forging, pressing etc.
60 Cutlery, tools etc.
61 Other metal products
62 Mechanical power equipment
63 General purpose machinery
64 Agricultural machinery
65 Machine tools
66 Special purpose machinery
67 Weapons & ammunition
68 Domestic appliances nec
69 Office machinery & computers
70 Electric motors & generators etc.
71 Insulated wire & cable
72 Electrical equipment nec
73 Electronic components
74 Transmitters for TV, radio & phone
75 Receivers for TV & radio
76 Medical & precision instruments
77 Motor vehicles
78 Shipbuilding & repair
79 Other transport equipment
80 Aircraft & spacecraft
81 Furniture
82 Jewellery & related products
83 Sports goods & toys
84 Miscellaneous manufacturing nec & recycling
85 Electricity production & distribution
86 Gas distribution
87 Water supply
88 Construction
89 Motor vehicle distribution & repair, automotive fuel retail

90	Wholesale distribution
91	Retail distribution
92	Hotels, catering, pubs etc.
93	Railway transport
94	Other land transport
95	Water transport
96	Air transport
97	Ancillary transport services
98	Postal & courier services
99	Telecommunications
100	Banking & finance
101	Insurance & pension funds
102	Auxiliary financial services
103	Owning & dealing in real estate
104	Letting of dwellings
105	Estate agent activities
106	Renting of machinery etc.
107	Computer services
108	Research & development
109	Legal activities
110	Accountancy services
111	Market research, management consultancy
112	Architectural activities & technical consultancy
113	Advertising
114	Other business services
115	Public administration & defence
116	Education
117	Health & veterinary services
118	Social work activities
119	Sewage & sanitary services
120	Membership organisations
121	Recreational services
122	Other service activities
123	Private households with employed persons

References

Anderson, A.W. & Manning, T.W., 1983. The Use of Input-Output Analysis in Evaluating Water Resource Development. *Canadian Journal of Agricultural Economics*, 31(1), 15-26.

Aroche-Reyes, F., 2003. A qualitative input-output method to find basic economic structures. *Papers in Regional Science*, 82(4), 581-590.

Ayres R. U., 1978. *Resources, Environment and Economics. Applications of the Materials/Energy Balance Principle*, New York: Wiley.

Ayres R.U., D'Arge R. & Kneese A. V., 1970. *Economics and the Environment: A Materials Balance Approach*, Washington: Resources for the Future.

Ayres R.U.; Ayres L., 2002. *A Handbook of Industrial Ecology*, Cheltenham: Edward Elgar.

Ayres R.U.; Simonis U., 1994. *Industrial Metabolism: Restructuring for Sustainable Development*, Tokyo: United Nations University Press.

Ayres, R. & Shapanka, A., 1976. Explicit technological substitution forecasts in long-range input-output models. *Technological Forecasting and Social Change*, 9(1-2), 113-138.

Ayres, R.U. & Kneese, A.V., 1971. Economic and Ecological Effects of a Stationary Economy. *Annual Review of Ecology and Systematics*, 2, 1-22.

Ayres, R.U. & Kneese, A.V., 1969. Production, Consumption, and Externalities. *The American Economic Review*, 59(3), 282-297.

Barker, T., 1981. Projecting economic structure with a large-scale econometric model. *Futures*,, 13(6), 458-467.

Barker, T. et al., 1980. The Cambridge multisectoral dynamic odel: An instrument for national economic policy analysis. *Journal of Policy Modeling*,, 2(3), 319-344.

Barker, T., Ekins, P. & Foxon, T., 2007. Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000â “2010. *Energy Economics*,, 29(4), 760-778.

Barker, T., Junankar, S. et al., 2007. Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995â “2005. *Energy Policy*,, 35(12), 6281-6292.

Cardenete, M.A. & Sancho, F., 2006. Missing links in key sector analysis. *Economic Systems Research*, 18(3), 319-325.

Carter, A.P., 1976. *Energy and the Environment. A Structural Analysis*, Brandeis.

Carter, A.P., 1974. Energy, Environment, and Economic Growth. *The Bell Journal of Economics and Management Science*, 5(2), 578-592.

Carter, A.P. & Petri, P.A., 1979. Aspects of a new world development strategy II: Factors affecting the long-term prospects of developing nations. *Journal of Policy Modeling*, 1(3), 359-381.

Daly, H., 2000. *Ecological economics and the ecology of economics : essays in criticism*, Cheltenham: Edward Elgar.

Dietzenbacher, E. & Velázquez, E., 2007. Analysing Andalusian Virtual Water Trade in an Input–Output Framework. *Regional Studies*, 41(2), 185 - 196.

Duchin, F., 1992. Industrial input-output analysis: implications for industrial ecology. *Proceedings of the National Academy of Sciences of the United States of America*, 89(3), 851-855.

Duchin, F., 2004. *Input-Output Economics and Material Flows*, Rensselaer Polytechnic Institute.

Duchin, F. & Szyld, D.B., 1985. A DYNAMIC INPUT-OUTPUT MODEL WITH ASSURED POSITIVE OUTPUT(*). *Metroeconomica*, 37(3), 269-282.

Duchin, F., 1986. Computers, Input-Output, and the Future. *Journal of Economic Issues*, 20(2), 499-507.

Duchin, F., 1994. *Household Use and Disposal of Plastics_an_Input_Output_Case_Study_for_New_York_City*, New York University.

Duchin, F., 1998. *Structural Economics: Measuring Change in Technology, Lifestyles and the Environment*, Island Press.

Duchin, F., 1990. The conversion of biological materials and wastes to useful products. *Structural Change and Economic Dynamics*, 1(2), 243-261.

Duchin, F. & Hertwich, E., 2003. Industrial Ecology. Available at: http://www.ecoeco.org/education_encyclopedia.php.

Ferrer, G. & Ayres, R.U., 2000. The impact of remanufacturing in the economy. *Ecological Economics*, 32(3), 413-429.

Fischer-Kowalski, M., 1998. Society's Metabolism: The Intellectual History of Materials

Flow Analysis, Part I, 1860-1970. *Journal of Industrial Ecology*, 2(1), 61-78.

Fischer-Kowalski, M. & Hattler, W., 1998. Society's Metabolism: The Intellectual History of Materials Flow Analysis, Part II, 1970-1998. *Journal of Industrial Ecology*, 2(4), 107-136.

Fontela, E., 1989. Industrial structures and economic growth: an input-output perspective. *Economic Systems Research*, 1(1), 45-68.

Forsund, F.R. & Strom, S., 1976. The generation of residual flows in Norway: an input-output approach. *Journal of Environmental Economics and Management*, 3(2), 129-141.

Gay, P.W. & Proops, J.L.R., 1993. Carbon dioxide production by the UK economy: An input-output assessment. *Applied Energy,*, 44(2), 113-130.

Giljum, S., 2004. Trade, Materials Flows, and Economic Development in the South: The Example of Chile. *Journal of Industrial Ecology*, 8(1-2), 241-261.

Giljum, S. & Hubacek, K., 2004. Alternative Approaches of Physical Input–Output Analysis to Estimate Primary Material Inputs of Production and Consumption Activities. *Economic Systems Research*, 16(3), 301 - 310.

Graedel, T.E. & Allenby, B.R., 2002. *Industrial Ecology*, Prentice Hall.

Gutmanis, I., 1975. Input-output models in economic and environmental policy analyses. *Proceedings of the IEEE*, 63(3), 431-437.

Herendeen, R. & Tanaka, J., 1976. Energy cost of living. *Energy,*, 1(2), 165-178.

Hewings, G.J.D. et al., 1989. Key sectors and structural change in the Brazilian economy: A comparison of alternative approaches and their policy implications. *Journal of Policy Modeling,*, 11(1), 67-90.

Hirschman, A., 1958. *The Strategy of Economic Development*, Yale University Press.

Hoekstra R., 2005. *Economic Growth, Material Flows and the Environment. New Applications of Structural Decomposition Analysis and Physical Input-Output Tables*, Edward Elgar.

Hoekstra, R. & van den Bergh, J.C., 2002. Structural Decomposition Analysis of Physical Flows in the Economy. *Environmental and Resource Economics*, 23(3), 357-378.

Janssen, R., 1993. *Multiobjective Decision Support for Environmental Management*, Kluwer Academic Publishers.

Jasny, N., 1962. The Russian Economic 'Balance' and Input-Output Analysis: A Historical Comment. *Soviet Studies*, 14(1), 75-80.

Kananen, I. et al., 1990. Multiple Objective Analysis of Input-Output Models for Emergency Management. *OPERATIONS RESEARCH*, 38(2), 193-201.

Kondo, Y. & Nakamura, S., 2005. Waste inputâ "output linear programming model with its application to eco-efficiency analysis. *Economic Systems Research*, 17(4), 393-408.

Kossov, V.V., 1964. Regional Input-Output Analysis in the U.S.S.R. *Papers in Regional Science*, 14(1), 175-181.

Lantner, R. & Carluer, F., 2004. Spatial dominance: a new approach to the estimation of interconnectedness in regional input-output tables. *The Annals of Regional Science*, 38(3), 451-467.

Lenzen M. & Foran B., 2001. An input-output analysis of Australian water usage. *Water Policy*, 3, 321-340.

Lenzen, M., 2003. Environmentally important paths, linkages and key sectors in the Australian economy. *Structural Change and Economic Dynamics,*, 14(1), 1-34.

Lenzen, M., 2009. Understanding virtual water flows: A multiregion input-output case study of Victoria. *Water Resour. Res.*, 45(9), W09416.

Leontief, W., 1970. Environmental Repercussions and the Economic Structure: An Input-Output Approach. *The Review of Economics and Statistics*, 52(3), 262-271.

Leontief, W., 1977a. Natural Resources, Environmental Disruption, and Growth Prospects of the Developed and Less Developed Countries. *Bulletin of the American Academy of Arts and Sciences*, 30(8), 20-30.

Leontief, W., 1977b. NATURAL RESOURCES, ENVIRONMENTAL DISRUPTION, AND THE FUTURE WORLD ECONOMY. *Journal of International Affairs*, 31(2), 267.

Leontief, W., 1936. Quantitative Input and Output Relations in the Economic Systems of the United States. *The Review of Economics and Statistics*, 18(3), 105-125.

Leontief, W., 1949. Recent Developments in the Study of Interindustrial Relationships. *The American Economic Review*, 39(3), 211-225.

Leontief, W., 1952. Some Basic Problems of Stuctural Analysis. *The Review of Economics and Statistics*, 34(1), 1-9.

Leontief, W., 1974. Structure of the World Economy. Outline of a Simple Input-Output Formulation. *The Swedish Journal of Economics*, 76(4), 387-401.

Leontief, W., 1977. *The Future of the World Economy: A United Nations Study*, Oxford University Press.

Leontief, W. & Duchin, F., 1986. *The Future Impact of Automation on Workers*, Oxford University Press USA.

Leontief, W.W. & Ford, D., 1972. Air Pollution and the Economic Structure: Empirical Results of Input-
Output Computations. In *A. Brody and A.P. Carter (eds) Input-Output Techniques*. Amsterdam: North-Holland.

Luptáčik, M. & Böhm, B., 1994. An environmental input-output model with multiple criteria. *Annals of Operations Research*, 54(1), 119-127.

Madlener, R. & Stagl, S., 2005. Sustainability-guided promotion of renewable electricity generation. *Ecological Economics,*, 53(2), 147-167.

Moffatt I. & Hanley N., 2001. Modelling sustainable development: systems dynamic and input-ouput approaches. *Environmental Modelling and Software with Environment Data News*, 16, 545-557.

Munda, G., 1995. *Multicriteria Evaluation in a Fuzzy Environment*, Heidelberg: Physica-Verlag.

Munda, G., 2005. Multiple Criteria Decision Analysis and Sustainable Development. In *Multiple-criteria decision analysis. State of the art surveys.* New York: Springer, pp. 953-986.

Nakamura, S., 1999. An interindustry approach to analyzing economic and environmental effects of the recycling of waste. *Ecological Economics*, 28(1), 133-145.

Nakamura, S. & Kondo, Y., 2006. A waste input-output life-cycle cost analysis of the recycling of end-of-life electrical home appliances. *Ecological Economics*, 57(3), 494-506.

Nakamura, S. & Kondo, Y., 2002. Recycling, landfill consumption, and CO2 emission: analysis by waste input–output model. *Journal of Material Cycles and Waste Management*, 4(1), 2-11.

Park, S., 1982. An input-output framework for analysing energy consumption. *Energy Economics*, 4(2), 105-110.

Peters, G.P. & Hertwich, E.G., 2006. Pollution embodied in trade: The Norwegian case.

Global Environmental Change, 16(4), 379-387.

Petri, P.A., 1977. An introduction to the structure and application of the United Nations world model. *Applied Mathematical Modelling*, 1(5), 261-267.

Polenske, K.R. & Lin, X., 1993. Conserving energy to reduce carbon dioxide emissions in China. *Structural Change and Economic Dynamics*, 4(2), 249-265.

Proops, 1984. Modelling the energy-output ratio. *Energy Economics,*, 6(1), 47-51.

Proops, J.L.R., 1977. Input-output analysis and energy intensities: a comparison of some methodologies. *Applied Mathematical Modelling,*, 1(4), 181-186.

Raa, T.T., 1986. Applied dynamic input-output with distributed activities. *European Economic Review*, 30(4), 805-831.

Rasmussen, P., 1956. *Studies in Intersectoral Relations*, North-Holland.

Rey, G. & Tilanus, C.B., 1963. Input-Output Forecasts for the Netherlands, 1949-1958. *Econometrica*, 31(3), 454-463.

Roy, B., 1985. *Methodologie multicritere d'aide a la decision*, Paris: Economica.

Schäfer, D. & Stahmer, C., 1989. Inputâ "Output Model for the Analysis of Environmental Protection Activities. *Economic Systems Research*, 1(2), 203-228.

Shmelev, S. & Powell, J., 2006. Ecological-economic modelling for strategic regional waste management systems. *Ecological Economics*, 59(1), 115-130.

Shmelev, S.E. & Rodríguez-Labajos, B., 2009. Dynamic multidimensional assessment of sustainability at the macro level: The case of Austria. *Ecological Economics*, 68(10), 2560-2573.

Simpson, D. & Tsukui, J., 1965. The Fundamental Structure of Input-Output Tables, An International Comparison. *The Review of Economics and Statistics*, 47(4), 434-446.

Söderbaum, P., 2000. *Ecological economics : a political economics approach to environment and development*, London: Earthscan.

Sonis, M. et al., 1995. Linkages, Key Sectors, and Structural Change: Some New Perspectives. *The Developing Economies*, 33(3), 243-246.

Sonis, M. & Hewings, G.J.D., 1998. Economic complexity as network complication: Multiregional input-output structural path analysis. *The Annals of Regional Science*, 32(3), 407-436.

Sonis, M. & Hewings, G.J., 1999. Economic landscapes: multiplier product matrix analysis for
multiregional IO systems. *Hitotsubashi Journal of Economics*, 40, 59-74.

Stone, R., 1984. Model design and simulation. *Economic Modelling*, 1(1), 3-23.

Suh S. (Ed), 2009. *Handbook of Input-Output Economics in Industrial Ecology*, Springer.

Suh, S., 2005a. Developing a sectoral environmental database for input–output analysis: the comprehensive environmental data archive of the US. *Economic Systems Research*, 17(4), 449 - 469.

Suh, S., 2005b. Theory of materials and energy flow analysis in ecology and economics. *Ecological Modelling*, 189(3-4), 251-269.

Tarancon Moran, M.�. & del Rio Gonzalez, P., 2007. A combined input-output and sensitivity analysis approach to analyse sector linkages and CO2 emissions. *Energy Economics*, 29(3), 578-597.

Tukker, A. et al., 2009. Towards a global multi-regional environmentally extended input-output database. *Ecological Economics*, 68(7), 1928-1937.

Vogt, W., Mickle, M. & Aldermeshian, H., 1975. A dynamic Leontief model for a productive system. *Proceedings of the IEEE*, 63(3), 438-443.

Wang, H. & Wang, Y., 2009. An input–output analysis of virtual water uses of the three economic sectors in Beijing. *Water International*, 34(4), 451 - 467.

Wang, L., MacLean, H.L. & Adams, B.J., 2005. Water resources management in Beijing using economic input-output modeling. *Canadian Journal of Civil Engineering*, 32, 753-764.