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 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 & Rodriguez-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 economy 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).

![Economy-Environment Interdependence](image)

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

<table>
<thead>
<tr>
<th>Country</th>
<th>Year, Referring To</th>
<th>Number of Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>USSR</td>
<td>1923/24</td>
<td>12 sectors</td>
</tr>
<tr>
<td>USA</td>
<td>1919</td>
<td>44 sectors</td>
</tr>
<tr>
<td>USA</td>
<td>1929</td>
<td>41 sector</td>
</tr>
<tr>
<td>USA</td>
<td>1947, 1958, 1963</td>
<td>400 sectors, 480 intermediate sectors</td>
</tr>
<tr>
<td>Norway</td>
<td>1948</td>
<td>175 sectors</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1948-1957</td>
<td>35 sectors</td>
</tr>
<tr>
<td>UK</td>
<td>1954, 1961</td>
<td>123 intermediate sectors</td>
</tr>
<tr>
<td>Hungary</td>
<td>1957</td>
<td>40 sectors</td>
</tr>
<tr>
<td>Poland</td>
<td>1957</td>
<td>20 sectors</td>
</tr>
<tr>
<td>USSR</td>
<td>1959</td>
<td>83 sectors</td>
</tr>
<tr>
<td>Brazil</td>
<td>1959</td>
<td>32 sectors</td>
</tr>
<tr>
<td>Brazil</td>
<td>1969, 1970</td>
<td>87 sectors</td>
</tr>
<tr>
<td>Estonia</td>
<td>1961</td>
<td>239 sectors</td>
</tr>
<tr>
<td>Lithuania</td>
<td>1961</td>
<td>239 sectors</td>
</tr>
<tr>
<td>Canada</td>
<td>1961</td>
<td>250 industries</td>
</tr>
<tr>
<td>Belorussia</td>
<td>1962</td>
<td>500 sectors</td>
</tr>
</tbody>
</table>
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 CO₂, NH₄, NOₓ. 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

<table>
<thead>
<tr>
<th>Author, year</th>
<th>Country of application</th>
<th>Sectoral Dimensions</th>
<th>Extensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Leontief 1970)</td>
<td>N/A</td>
<td>2x2</td>
<td>1 pollutant, agriculture and manufacturing</td>
</tr>
<tr>
<td>(Leontief &amp; Ford 1972)</td>
<td>USA</td>
<td>90 sectors</td>
<td>5 residuals, 1 recipient (air), 11 final demand categories,</td>
</tr>
<tr>
<td>(Leontief 1974)</td>
<td>World</td>
<td></td>
<td>45 sectors, 40 minerals and fuels, 30 pollutants</td>
</tr>
<tr>
<td>(Forsund &amp; Strom 1976)</td>
<td>Norway</td>
<td>86 sectors</td>
<td>35 types of residuals, 28 final demand categories</td>
</tr>
<tr>
<td>(J. L. R. Proops 1977)</td>
<td>UK</td>
<td>3x3</td>
<td>energy intensities</td>
</tr>
<tr>
<td>(Luptáčík &amp; Böhm 1994)</td>
<td>N/A</td>
<td></td>
<td>MCDA, trade-off between economic goals and the</td>
</tr>
</tbody>
</table>
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 CO₂ 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.
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 CO₂, CH₄, 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

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Sectors</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Extraction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other mining and quarrying</td>
<td>49.6%</td>
</tr>
<tr>
<td></td>
<td>Oil and gas extraction</td>
<td>28.0%</td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>17.2%</td>
</tr>
<tr>
<td>Water publicly supplied</td>
<td>Water supply</td>
<td>32.4%</td>
</tr>
<tr>
<td>Water directly abstracted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sector</td>
<td>CO₂</td>
<td>CH₄</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Electricity production and distribution</td>
<td>33.0%</td>
<td></td>
</tr>
<tr>
<td>Fishing</td>
<td>10.8%</td>
<td></td>
</tr>
<tr>
<td>Gas distribution</td>
<td>9.0%</td>
<td></td>
</tr>
<tr>
<td>Fish and fruit processing</td>
<td>5.1%</td>
<td></td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td><strong>Electricity production and distribution</strong></td>
<td><strong>36.0%</strong></td>
</tr>
<tr>
<td>Air transport</td>
<td>7.6%</td>
<td></td>
</tr>
<tr>
<td>Other land transport</td>
<td>6.0%</td>
<td></td>
</tr>
<tr>
<td><strong>CH₄</strong></td>
<td><strong>Sewage and sanitary services</strong></td>
<td><strong>42.5%</strong></td>
</tr>
<tr>
<td>Agriculture</td>
<td>31.5%</td>
<td></td>
</tr>
<tr>
<td>Gas distribution</td>
<td>11.3%</td>
<td></td>
</tr>
<tr>
<td>Coal extraction</td>
<td>10.9%</td>
<td></td>
</tr>
</tbody>
</table>

Figures 3 and 4 depict final demand and CO₂ 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.
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 vehicles, hotels and catering, public administration and defence, health and veterinary services, banking and finance.

CO₂ adjusted forward and backward linkage coefficients for the major industries depicted in Figure 3, give us a different picture. The most CO₂ forward and backward linked sector is Electricity production and distribution, other key sectors in relation to CO₂ 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.
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.
When the economic system is considered from the point of view of associated emissions of NOx (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: Electricity Production and Distribution, Fish and Fruit Processing, Fishing and so on. (Figures 6 and 7).
Figure 6. NOx adjusted forward and backward linkage coefficients, UK, 2002
Figure 7. Water adjusted public 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 multicriteria 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:

1) pairwise comparison of alternatives;
2) aggregation of all criteria;
3) 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 N x N matrix $R = (r_{ij})$, i.e.:

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

$r_{ij}=1$ 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 equal to ($\sim$)
4) exactly equal to ($=$)
5) less than ($<$)
6) much less than ($\ll$).

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 $\alpha$), 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 (Luptáčík & 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

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

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 CO₂, CH₄, NOₓ, 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, CO₂ emissions and NOₓ 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. $\alpha=0.1$ - weak sustainability setting
Annex 1. $\alpha=0.5$ - neutrality setting
Annex 1. $\alpha=0.9$ - strong sustainability setting

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
Soap & toilet preparations
Other chemical products
Man-made fibres
Rubber products
Plastic products
Glass & glass products
Ceramic goods
Structural clay products
Cement, lime & plaster
Articles of concrete, stone etc.
Iron & steel
Non-ferrous metals
Metal castings
Structural metal products
Metal boilers & radiators
Metal forging, pressing etc.
Cutlery, tools etc.
Other metal products
Mechanical power equipment
General purpose machinery
Agricultural machinery
Machine tools
Special purpose machinery
Weapons & ammunition
Domestic appliances nec
Office machinery & computers
Electric motors & generators etc.
Insulated wire & cable
Electrical equipment nec
Electronic components
Transmitters for TV, radio & phone
Receivers for TV & radio
Medical & precision instruments
Motor vehicles
Shipbuilding & repair
Other transport equipment
Aircraft & spacecraft
Furniture
Jewellery & related products
Sports goods & toys
Miscellaneous manufacturing nec & recycling
Electricity production & distribution
Gas distribution
Water supply
Construction
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


