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

Stanislav Edward Shmelev*[1]

The paper assesses the sustainability of investment in various economic sectors, with the aim of minimizing resource use and generation of emissions. The broad development focus of the paper and the potential for the proposed methodology to be applied in many different countries make it a useful methodological contribution to the global sustainability debate. The UK case is taken for illustration purposes, and (given the availability of the necessary data) this methodology could be applied in countries with various economic structures and specialisations. An environmentally extended static 123-sector UK input–output model is used, linking a range of physical flows (domestic extraction, use of water, and emissions of CO_2, CH_4, NO_x) with the economic structure of the UK. A range of environmentally adjusted forward and backward linkage coefficients has been developed, adjusted according to final demand, domestic extraction, publicly supplied and directly abstracted water, amd emissions of CO_2 and $NO_{x,}$. The data on the final demand-adjusted and environmentally adjusted forward and backward linkage coefficients were used in a multi-criteria decision-aid assessment, employing a NAIADE method in three different sustainability settings. The assessment was constructed in such a way that each sector of the UK economy was assessed by means of a panel of sustainability criteria, maximizing economic effects and minimizing environmental effects. This type of multi-criteria analysis, applied here for the first time, could prove to be a valuable basis for similar studies, especially in the developing world, where trade-offs between economic development and environmental protection have been the subject of considerable debate.

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1. Introduction

Three key elements seem to be crucial for socio-ecological transformation if our society is to achieve sustainable development, overcome growing energy and resource requirements and rising volumes of emissions and wastes, and facilitate the change towards renewable energy sources and conservation of biodiversity. Firstly, this is a concept of industrial ecology (Graedel and Allenby 2002), which highlights the importance of intersectoral flows of matter and energy required for the production of goods and services, analysed in detail throughout the whole lifecycle of the given product or service, or a whole regional or national system. Secondly, it is a system of tools for decision making (So□derbaum 2000) based on multi-criteria methods which, when applied at different levels, would shift the patterns of decision making towards decisions that are more socially equitable and more environment-friendly, as well as economically sound. 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, 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 quantitative growth. The idea of incommensurability of values, incorporated in the concept of sustainable development, has led to the development of new alternative sustainable-development assessment approaches (Shmelev and Rodríguez-Labajos 2009).

2. Industrial ecology: the study of interactions between the economy and the environment

The concept of industrial ecology emerged in several places independently, a phenomenon which is excellently described in two historical overviews of the development of this field (Fischer-Kowalski 1998; Fischer-Kowalski and Hattler 1998). The idea of industrial ecology was first proposed by Watanabe in a project devoted to the study of the resource-dependency of the Japanese economy (Duchin and Hertwich 2003), and a little later Robert Ayres independently developed the principles of this emerging discipline (Ayres 1978; Ayres R.U. and Ayres L. 2002). Robert Ayres has been one of the true pioneers in the analysis of economy–environment interactions (Figure 1): a formal mathematical framework for tracing residual flows in the econonomy was offered in Ayres and Kneese 1969; ideas of a stationary state economy were explored in Ayres and Kneese 1971; ideas about the interaction between the economy and the environment resulted in a substantial book, Ayres et al. 1970. These ideas were clearly influenced by the work of Wassily Leontief in the field of input–output analysis of the US 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, and 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_2 emissions.

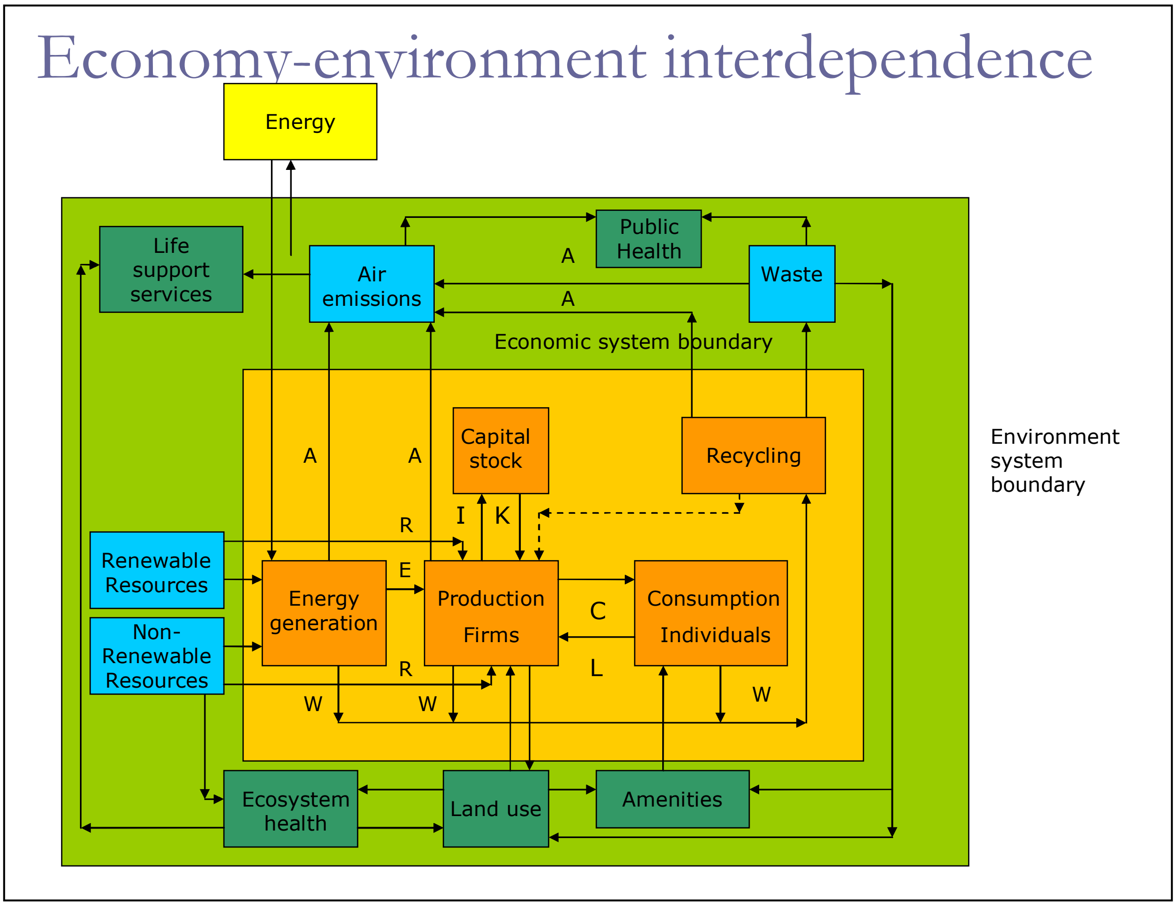


Figure 1 presents a schematic description of material and energy flows in the national economy. The outer light-green box depicts the boundaries of the environment system, with a yellow box ("Energy") responsible for the transfer of solar energy to ecosystems and humans. The inner dark-yellow box represents the economic system, forming part of a wider environmental system, and constrained by the limitation of the environmental system. The principle of embeddedness of the economic system in 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 natural ecological metabolic processes. Light-blue boxes in the chart represent stocks of renewable and non-renewable resources taken from the natural environment, and emissions and waste emitted into 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 the economic system represent the key factors that should be taken into account when analysing 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 impact that could be adjusted in each individual case. It was successfully applied to the analysis of the sustainability of regional waste-management systems (Shmelev and Powell 2006). When such a range of aspects of the development of a given regional or national system is considered, it seems desirable to use special multi-criteria methods to support decisions at all levels of the decision-making process, which will be covered in the next section of the paper.

Different countries started to develop input–output tables after the publication of the first analysis to balance the national economy of the USSR, and its subsequent criticism by Leontief (Table 1).

Table 1. National input–output tables

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

Tables for the 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), the USSR (1959), and Brazil (1959) continued the trend. The resolution of the input–output tables varied significantly: the first tables for the USA contained 44 and 41 sectors respectively, while the table for the Netherlands contained 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, and tables for Japan, Estonia, Lithuania, and Belorussia included 399, 239, 239, and 500 sectors respectively.

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

The environmentally extended input–output applications began to develop in the 1970s, following the original publication by Leontief (Table 2). They covered the following issues: energy and the environment (Carter 1974; Carter 1976; Herendeen and Tanaka 1976; J. L. R. Proops 1977; Park 1982; Proops 1984; Gay and Proops 1993; Polenske and Lin 1993); materials balance and materials flows (Duchin 2004; Giljum 2004; Hoekstra. 2005; Tukker et al. 2009; Suh (ed.) 2009); water (Anderson and Manning 1983; Lenzen and Foran 2001, L. Wang et al. 2005; Dietzenbacher and Velázquez 2007; Lenzen 2009; H. Wang and Y. Wang 2009); waste (Leontief 1977b; Duchin 1990; Duchin 1994; Nakamura 1999; Nakamura and Kondo 2002; Kondo and Nakamura 2005; Nakamura and Kondo 2006); and environmental policy analysis (Gutmanis 1975). The UN global model project has stimulated significant interest in the analysis of the environmental consequences of economic development and effects of technological innovation (Leontief 1977c; Ayres and Shapanka 1976; Petri 1977; Carter and Petri 1979; Leontief and Duchin 1986). Substantial projects focused on the application of input–output analysis to national economies for policy analysis began 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; Duchin and Szyld 1985; Raa 1986). Environmentally extended input–output analysis of changes in the world economy has been carried out by Leontief and Duchin 1986; Duchin 1986; Fontela 1989; and Schäfer and Stahmer 1989. Later, this framework was extended to include material flows (Duchin 2004), other pollutants (Duchin 1994; 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).

Table 2. Major contributions to environmentally extended input–output analysis

Author, year	Country of application	Sectoral dimensions	Extensions
Leontief, 1970	N/A	2 x 2	1 pollutant, agriculture, and manufacturing
Leontief and 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 and Strom, 1976	Norway	86 sectors	35 types of residual, 28 final-demand categories
Proops, 1977	UK	3 x 3	energy intensities
Barker, 1981	UK	40 sectors	econometrics, annual time series 1954–1979, and cross-section data in the form of input–output tables for 1954, 1963, 1968, 1974
Luptáčik and 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
Duchin, 1992	N/A	4 x 4	industrial ecology
Gay and Proops, 1993	UK	38 sectors	CO_2
Sonis and Hewings, 1998	Indonesia	5 sectors	structural path analysis, SAM
Nakamura, 1999	Netherlands	20 sectors	waste, recycling, and CO_2 emissions
Ferrer and Ayres 2000	France	30	waste, remanufacturing
Moffatt and Hanley, 2001	Scotland	28 sectors	12 pollution types
Hoekstra and 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 and Hubacek, 2004	Germany	3 x 3	primary material inputs
Lantner and Carluer, 2004	France	36 x 36	spatial dominance: 6 regions, 6 sectors each
Suh, 2005b	N/A		MFA and energy
Suh, 2005a	USA	500 sectors	lifecycle input–output
Peters and Hertwich, 2006	Norway	49 sectors	international trade, embodied CO_2
Cardenete and Sancho, 2006	Spain, 1995	10 sectors	SAM
Tarancon Moran and del Rio Gonzalez, 2007	Spain	44 sectors	CO_2 emissions

In his pioneering article (Lenzen 2003), Lenzen introduced the concept of environmentally important paths, linkages, and key sectors in the macroeconomic framework. Historically Rasmussen was the first 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 and Hewings 1999). Lenzen (Lenzen 2003) for the first time introduced the idea of environmentally adjusted forward and backward inter-industry linkages, which are designed to highlight the sectors that have higher than average propensity to cause resource extraction and emissions across the economy. Sectors with a forward-linkage coefficient higher than 1 tend to produce a higher than average impact "downstream" in their supply chain. Similarly, sectors with a backward-linkage coefficient larger than 1 tend to produce higher than average impact on the economy "upstream" in their supply chain. Sectors with both a forward-linkage coefficient and a backward-linkage coefficient higher than 1 are usually referred to as "key sectors". 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, and NO_x. Environmentally adjusted forward and backward linkages are calculated here for all the six mentioned environmental aggregates, to illustrate the pattern of direct and indirect effects of investing in particular sectors of the UK economy as of 2000.

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

Integration of economic input–output analysis and 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 environmental key-sector analysis. Taking into account physical flows is a major advantage of this approach, because it allows us to look beyond the 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 when analysing the economy-wide environmental effects of government investment programmes in times of crisis.

3. Environmentally extended input–output modelling

The static UK input–output model created by the author was used in this paper with extensions of resource and environmental flows. The input–output 123-sector tables referring to the year 2002 were obtained from the UK Office for National Statistics; the full sector classification can be seen in Annex 2 of this paper. It should be noted that the results of the subsequent analysis should be treated as a first approximation, because not all elements of the UK input–output table are available to the public, due to confidentiality regulations. The water accounts of the UK had to be adjusted, because they do not provide the necessary detail, and further disaggregation was carried out by the author. The data on material flows have been obtained from the MOSUS project, in which the author took an active part by developing the global database of material flows for 1980–2003, which included all countries of the world and approximately 400 types of flow according to EU guidelines (Shmelev and Giljum, 2004). Data on UK CO_2 emissions as well as data on CH_4 and NO_x emissions come from the UK Office for National Statistics.

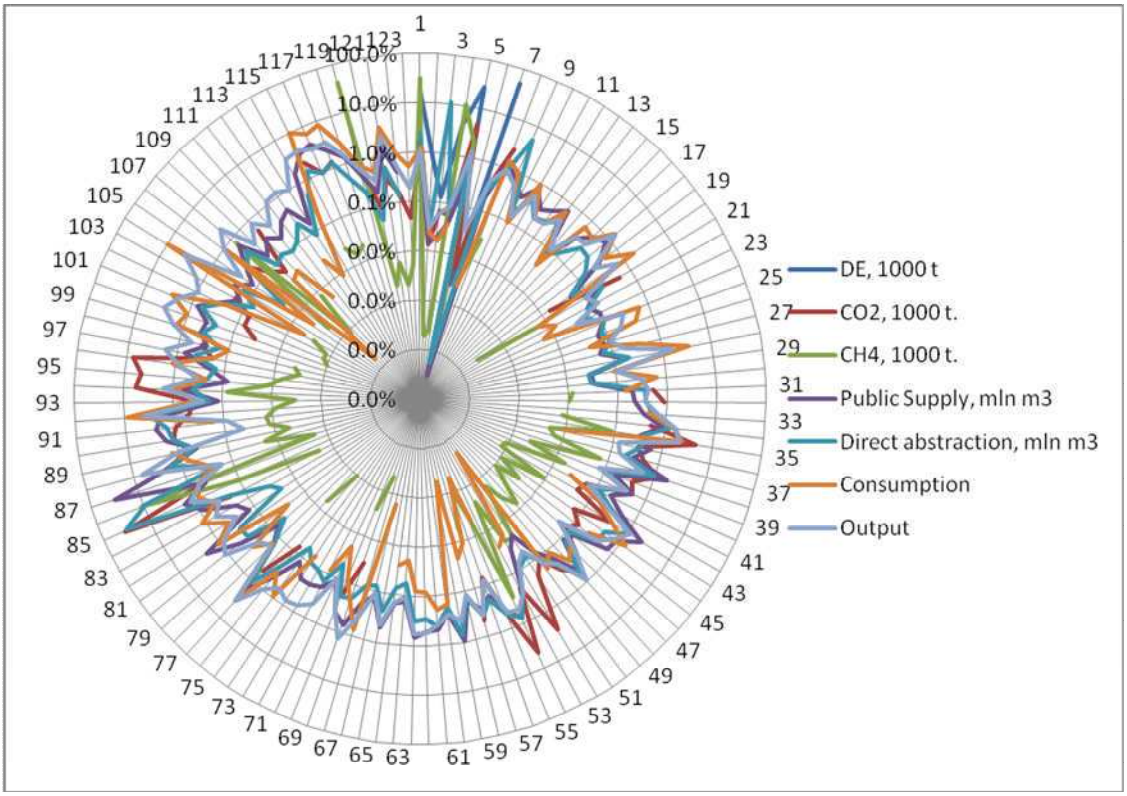


Figure 2. Economic and physical flows in the UK economy (123 sectors), 2002

An integrated illustration of the economic and environmental flows in the UK economy is presented in Figure 2. Each economic sector (the names and respective numbers are given 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 and CH_4, consumption, and economic output, presented on the logarithmic scale. Table 3 presents the most relevant sectors (with shares greater than 5 per cent) in terms of their direct environmental and economic effects, with their 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%

4. Environmentally adjusted forward and backward linkages in the UK economy

Figures 3 and 4 depict final-demand-adjusted and CO_2-adjusted coefficients of forward and backward linkages which characterized the national economy of the United Kingdom in 2002 from the point of view of the 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 respective value of both forward and backward linkage coefficients is greater than 1. The corresponding sector names and numbers can be found in Annex 2.

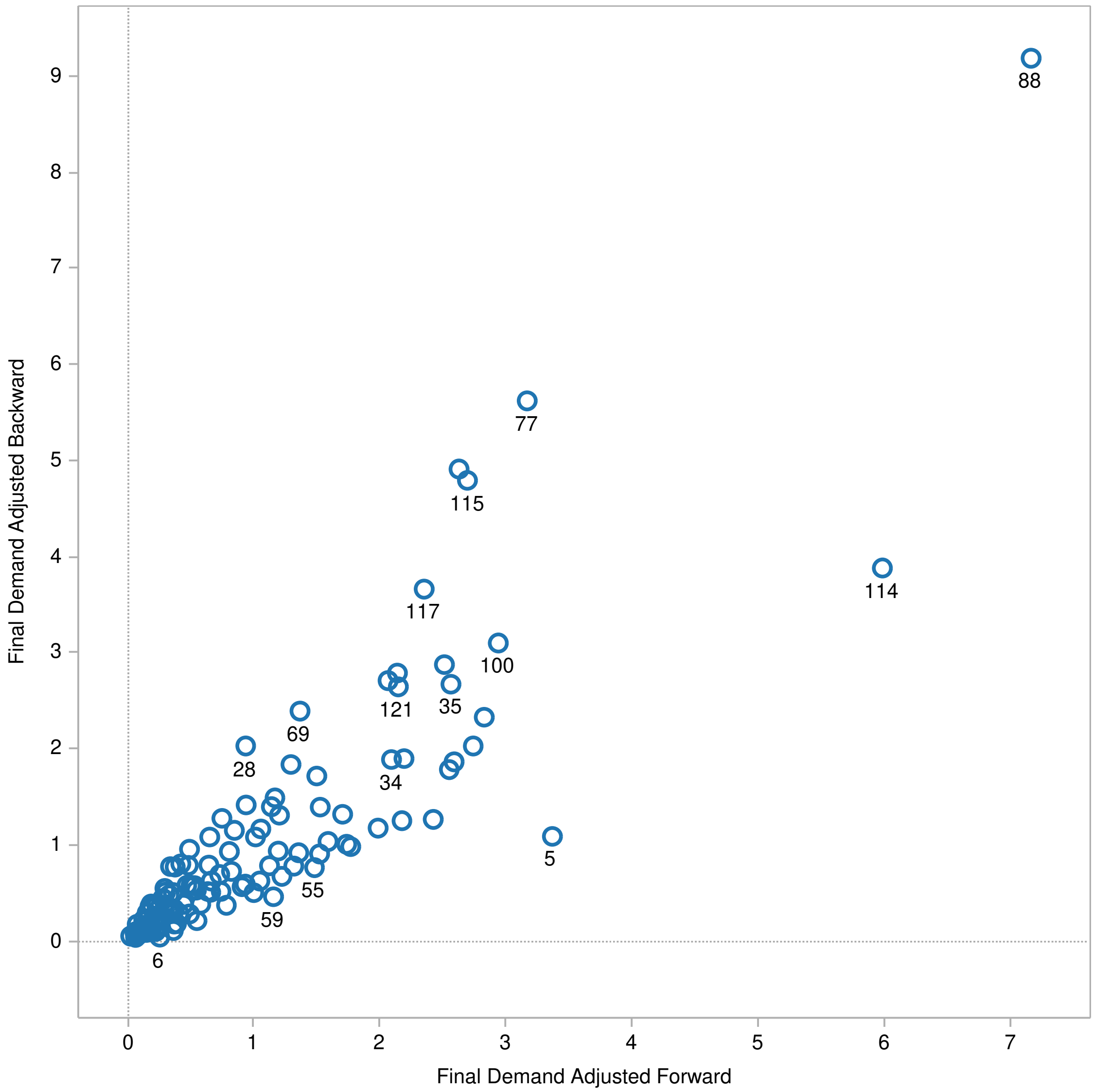


Figure 3. Final-demand-adjusted forward and backward linkage coefficients, labelled by sector, UK, 2002

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

CO_2-adjusted forward and backward linkage coefficients for the major industries depicted in Figure 4 give us a different picture. The most forward- and backward-linked sector in terms of CO_2 emissions 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 oil and gas extraction is much higher than the backward linkage, given the role that oil and gas play as fuels in the transport sector and other sectors. The reverse applies to air transport, due to the amount of fuel that is used on flights.

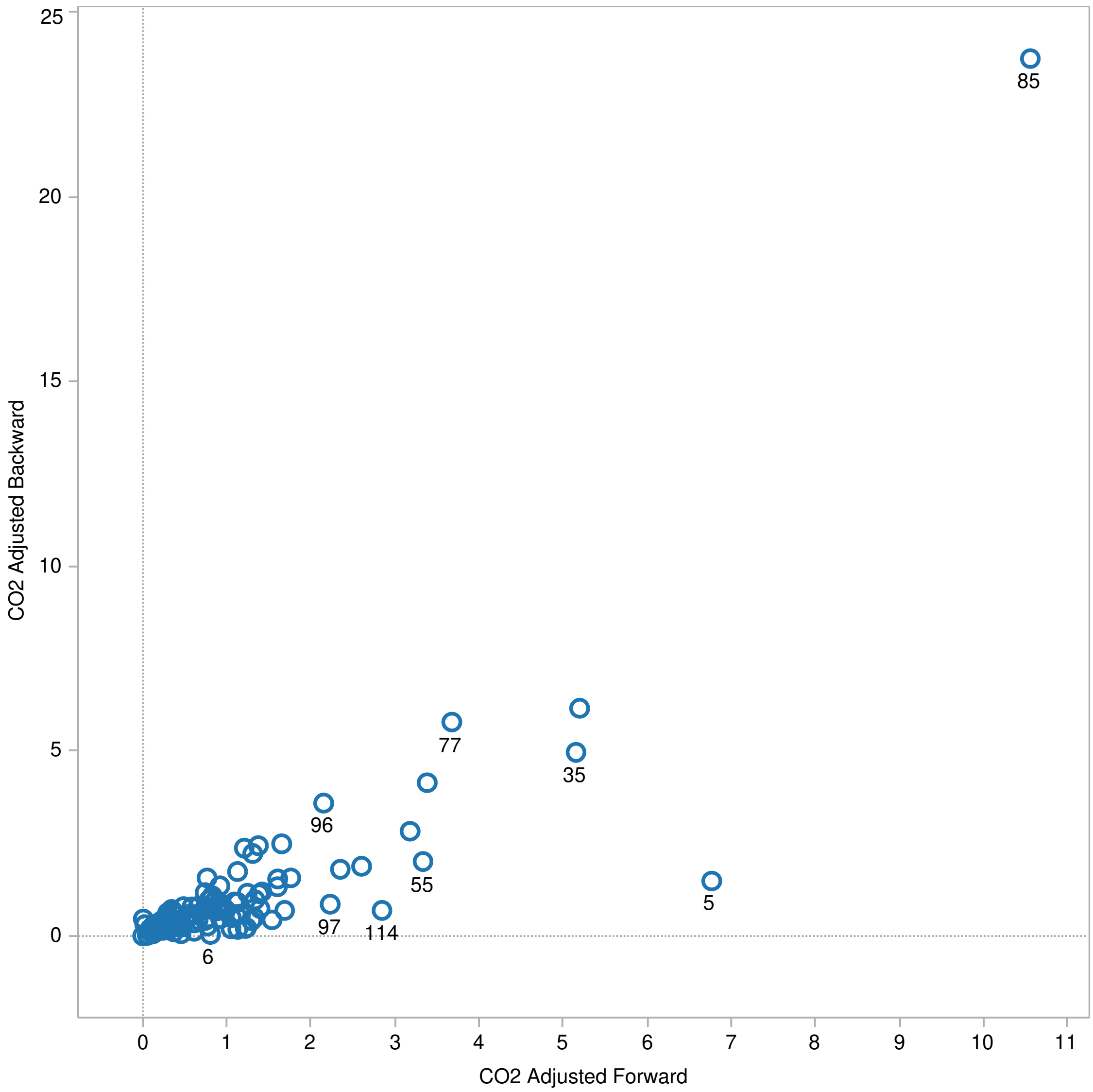


Figure 4. CO_2-adjusted forward and backward linkage coefficients, labelled by sector, UK, 2002

Key sectors in the environmental sense, when domestic extraction is taken as a basis for weighting the coefficients (Figure 5), 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 the oil and gas sector, the domestic-extraction-adjusted forward-linkage coefficient is 9,53, and the 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 sector's own domestic-extraction impact. Respective interpretation can be applied to the backward-linkage coefficients.

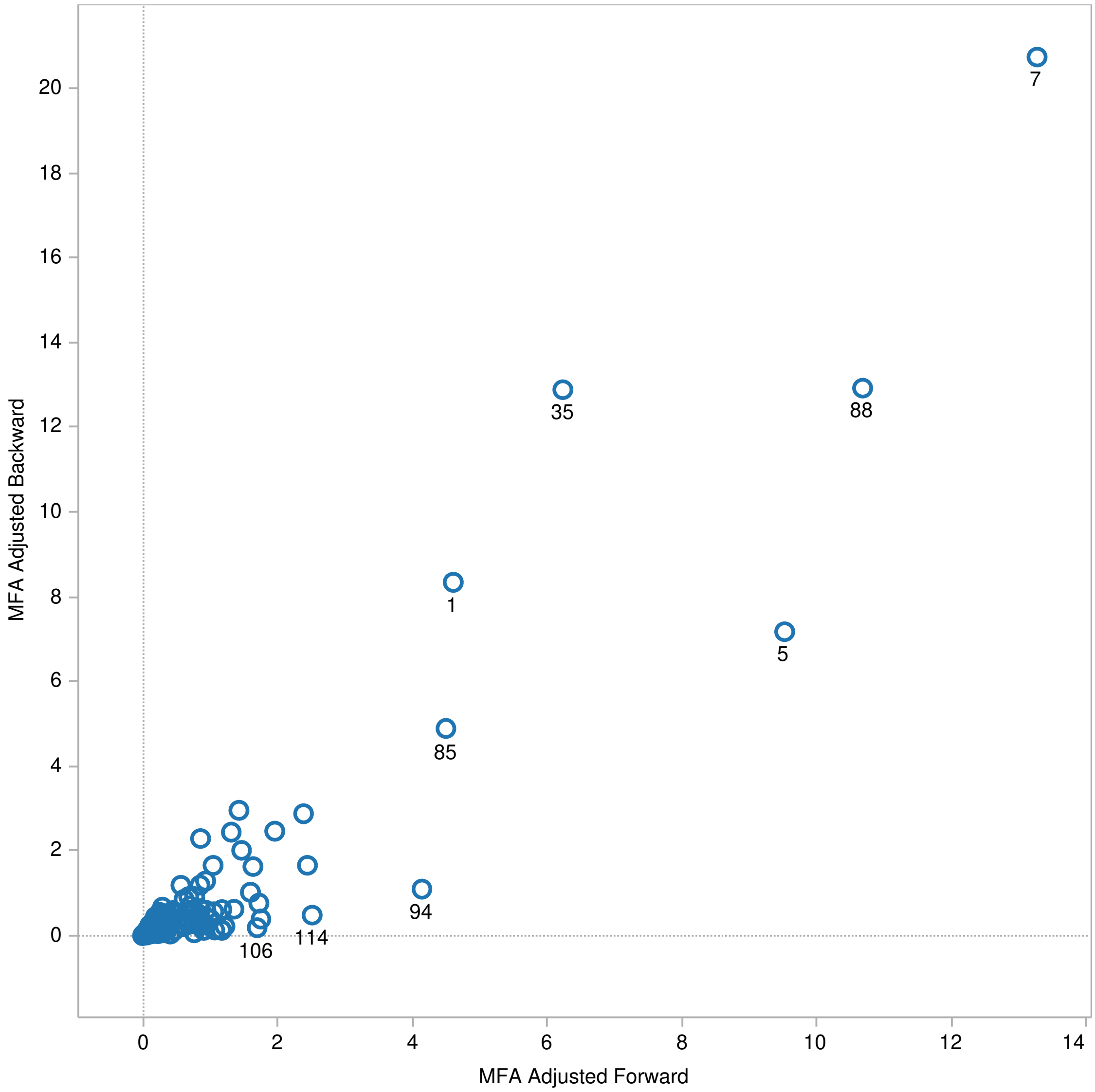


Figure 5. Domestic-extraction-adjusted forward and backward linkage coefficients, labelled by sector, UK, 2002

When the economic system is considered from the point of view of associated emissions of NO_x (Figure 6), the following pattern is produced. The sector characterized by the greatest potential to influence the generation of NO_x 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 7 and 8).

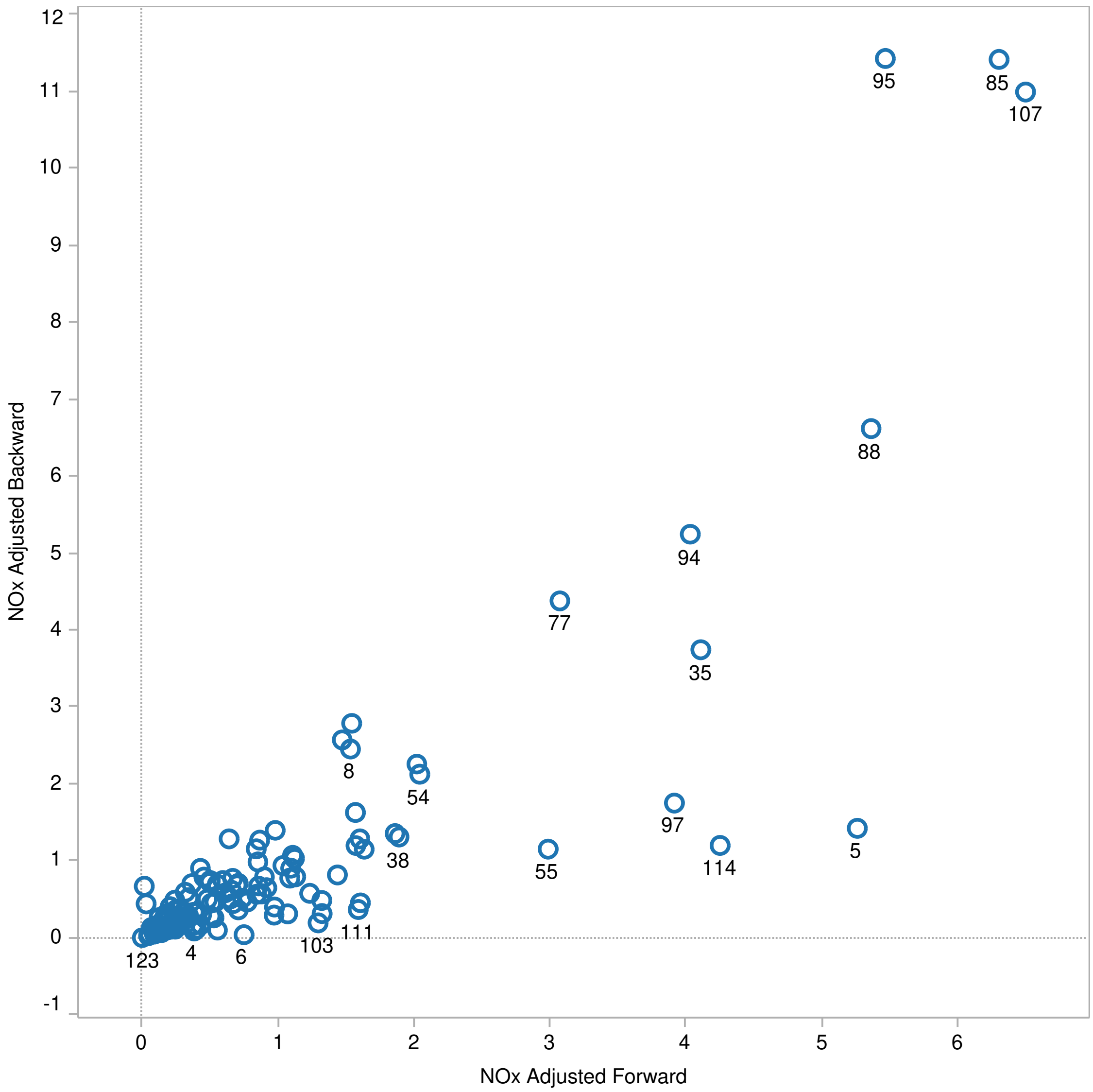


Figure 6. NO_x-adjusted forward and backward linkage coefficients, UK, 2002

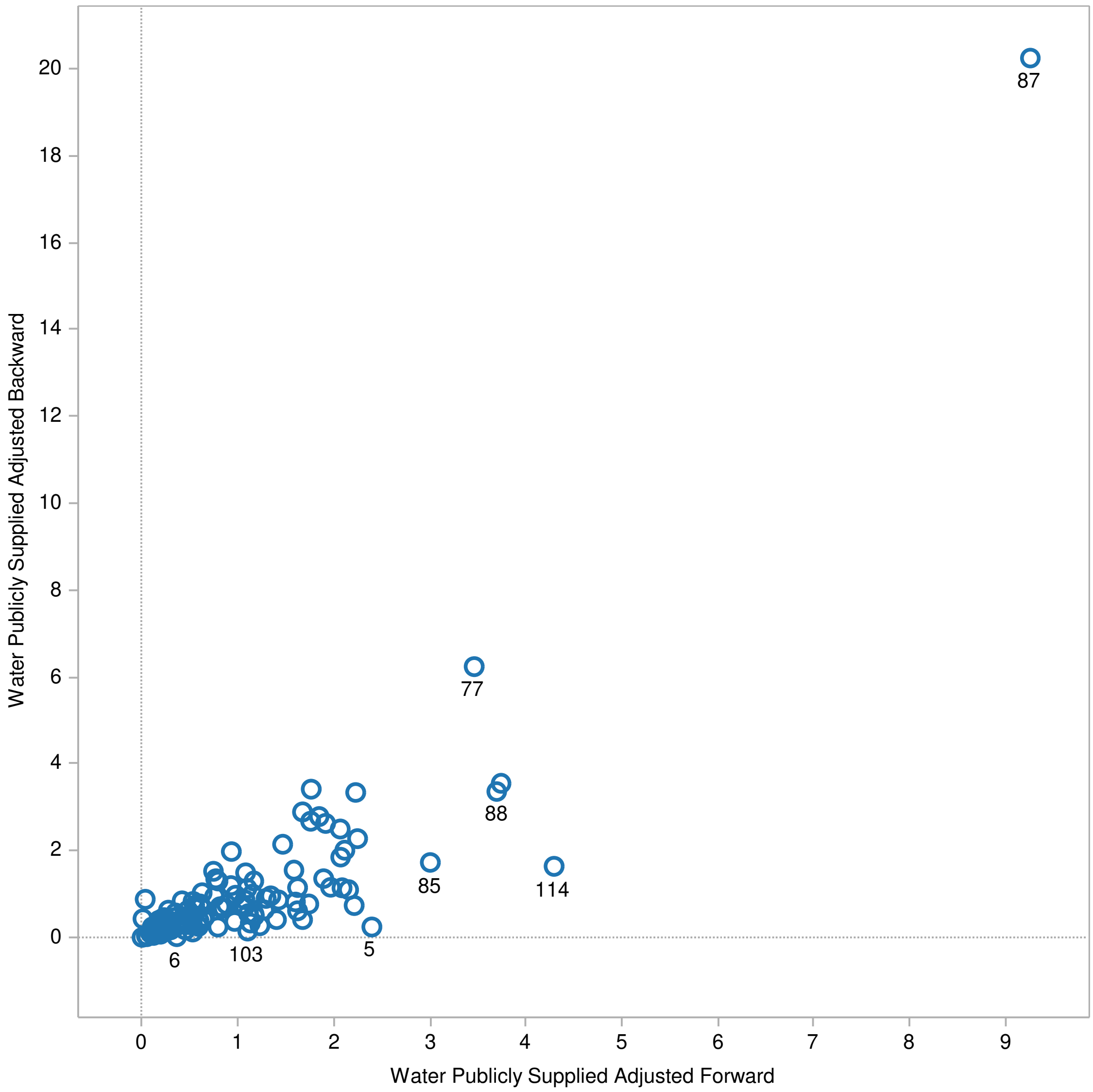


Figure 7. Publicly-supplied-water-adjusted forward and backward linkage coefficients, UK, 2002

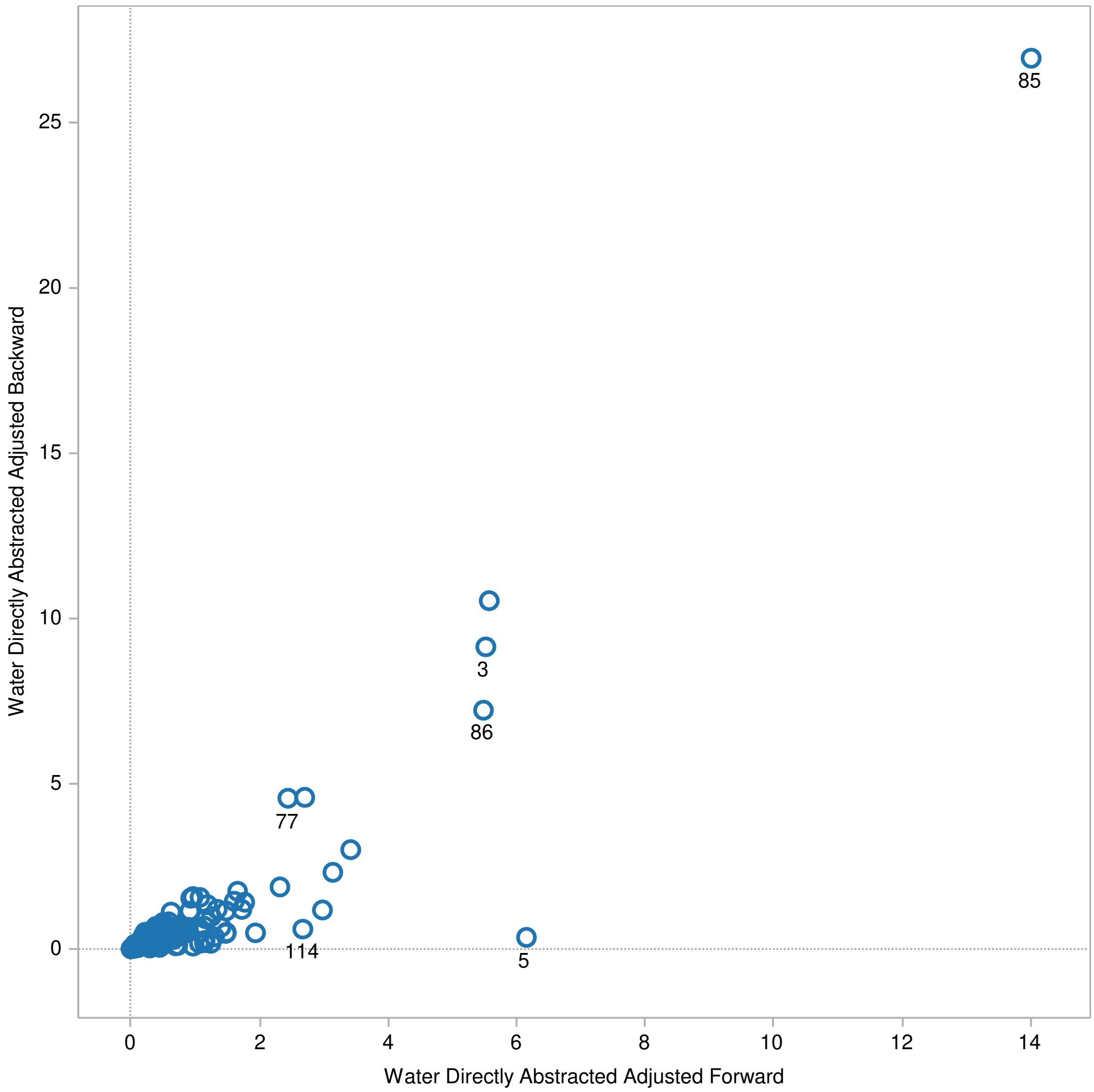


Figure 8. Directly-abstracted-water-adjusted forward and backward linkage coefficients, labelled by sector, UK, 2002

5. Macro sustainability assessment with MCDA

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 levels, taking into account a range of criteria simultaneously. Such methods, usually referred to as multi-criteria decision aid (MCDA) methods, 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 and Ayres (2000), applying these methods to regional problems; by Roy (1985), the author of one of the most famous families of multi-criteria methods, outranking methods "ELECTRE"; and by Janssen (1993), who developed a decision-support tool called DEFINITE and is the author of the method known as NAIADE, based on fuzzy logic. There is an extensive body of work covering the use of multi-criteria methods in decision making. A range of multi-criteria programming methods has been developed to deal with well-structured and quantitatively described problems. Numerous applications exist for regional problems, e.g. waste management (Shmelev and Powell 2006) and renewable energy (Madlener and Stagl 2005). The novel application of such methods to macro sustainability assessment has been offered in Shmelev and Rodríguez-Labajos 2009).

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.

Novel Approach to Imprecise Assessment and Decision Environment (NAIADE) is a discrete muilti-criteria method whose impact (or evaluation) matrix may include either crisp, stochastic, or fuzzy measurements of the performance of alternatives 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 into three main steps:

- pair-wise comparison of alternatives;
- aggregation of all criteria;
- 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 equal to (~)
4) exactly equal to (=)
5) less than (<)
6) much less than (<<).

Given the information on the pair-wise 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 webs of domination relationships among alternatives and presents them in a useful graphical form. The main distinctive feature of NAIADE, which was particular important for our analysis, is its 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 a more detailed description of the NAIADE method, interested readers are referred to Munda 1995.

6. Application of MCDA methods for sustainability analysis

The only known application of MCDA tools in the input–output context is reported in Luptáčik and Böhm 1994. The authors use the input–output model as a basis for a multi-criteria 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 have been used in the multi-criteria 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, for the weak, neutral, and strong sustainability settings, which can be seen in detail in Annex 1.

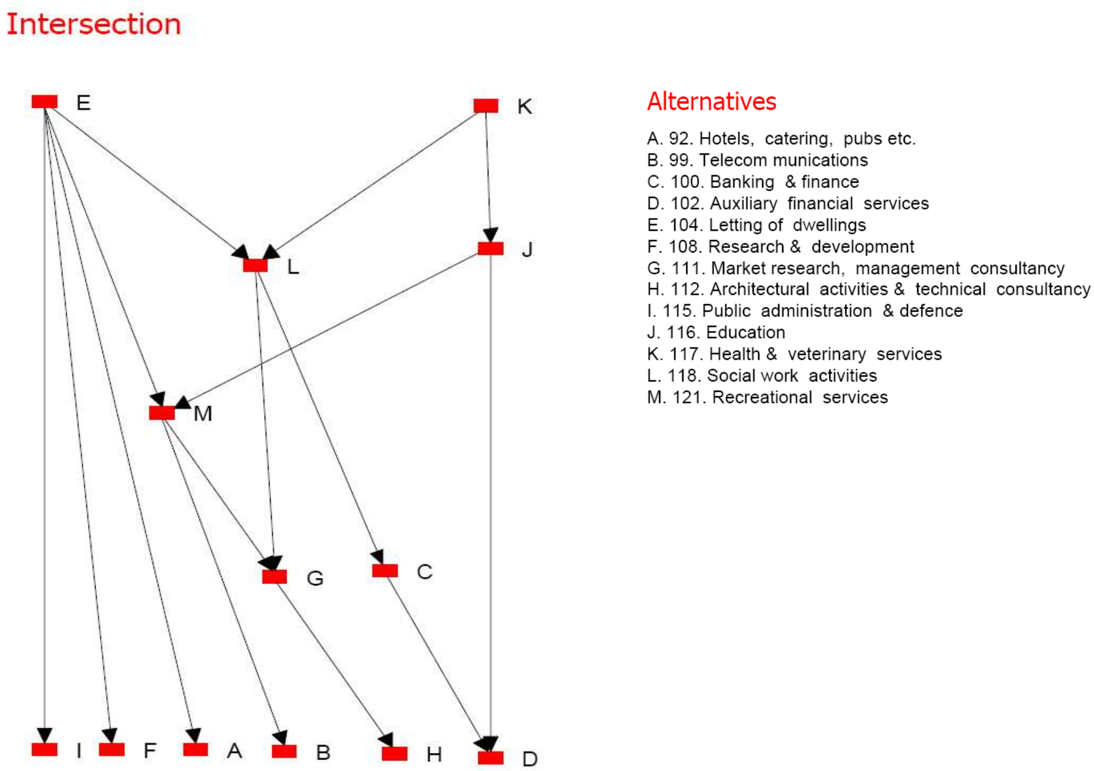


Figure 9. The web of domination relationships, most sustainable economic sectors (final demand, domestic extraction, CO_2, NO_x, adjusted linkages), UK, 2002

Each of the UK economic sectors was taken into account in the MCDA assessment, with eight coefficients each respectively: forward and backward linkage coefficients adjusted for final demand, domestic extraction, CO_2 and NO_x. It was assumed that it is in the interests of society to maximize the final-demand-adjusted economic multiplier characteristics of certain sectors, at the same time minimizing direct and induced material extraction, CO_2 emissions and NO_x emissions. The web, depicted in Figure 9, could be interpreted in the following way: economic sectors E (104, Letting of Dwellings) and K (117, Health and Veterinary Services) turned out to be the most sustainable, dominating all the other sectors and occupying the top positions in the web under the neutrality assumption about sustainability (the results change in weaker or stronger sustainability settings). Sectors L (118, Social work activities) and J (116, Education) were the next from the top in terms of sustainability criteria outlined here, while sector M (121, Recreational Services) occupied the next "layer in the hierarchy"; however, L and J or L and M are not comparable with each other (there are no connecting arrows between the two in each pair). An arrow in such a diagram shows the existence of the domination relationship between the alternatives in question; the direction of such an arrow denotes the direction of the domination relationship (in other words the arrow between J and M indicates that J dominates M); the lack of such an arrow points to incomparability.

Sectors G (111, Market research, management consultancy) and C (100, Banking and finance) occupied the layer at the bottom of the middle of the web, and finally sectors I (115, Public administration and defence), F (108, Research and Development), A (92, Hotels, catering and pubs), B (99, Telecommunications), H (112, Architectural activities, etc.), and D (102, Auxiliary financial services) occupied the bottom of the web of domination relationships and were the least sustainable of the set of sectors identified in this example. It should be stressed that the parameter α plays a crucial role in determining the shape of the resulting web of domination relationship.

Table 4 presents a 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
α =0.1 (weak sustainability)	104 Letting of Dwellings 121 Recreational Services 118 Social Work Activities 116 Education 102 Auxiliary Financial Services
α =0.5 (neutrality)	104 Letting of Dwellings 117 Health and Veterinary Services 116 Education 121 Recreational Services 118 Social Work Activities
α =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 of the differences between the strong and the weak sustainability in the NAIDE applications, the reader is referred to Shmelev and Rodríguez-Labajos 2009, the key difference being the ease of compensation among the sustainability criteria in the case of weak and strong complementarity and less pronounced compensation in the strong sustainability setting.

It can be seen from Table 4 that such sectors as 116 (Education), 117 (Health and Veterinary Services), 118 (Social Work Activities), 104 (Letting of Dwellings), and 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, in the sense of both direct effects and indirect effects, thereby not inflicting a heavy resource-use or pollution load across the whole spectrum of economic sectors. This result is extremely important for the preparation of economic recovery programmes by the UK government, focused in the neo-Keynesian sense on stimulating economic recovery. One would hope that the current economic crisis will be seen as an opportunity to concentrate not only on economic recovery, but also more widely on resource use and environmental impacts and the strategic environmental modernisation of the economy. In any case, any reduction in budgets for education or health care according to these results is completely unjustified and would be harmful for the economy in the long run, especially taking the sustainability perspective into account.

7. Conclusions

As our application shows, a 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" in terms of both direct and indirect impacts. The unique aspect of this application is in its use of environmentally adjusted forward and backward linkage coefficients which show the effects that are being produced through the web of intersectoral linkages.

This paper has presented a novel way of assessing the relative sustainability of investment in particular economic sectors from the point of view of resource use and generation of emissions. The research can be disaggregated into the following three steps: an environmentally extended, static 123-sector UK input–output model has been created, linking a range of physical flows (domestic extraction, use of water, emissions of CO_2, CH_4, and NO_x) with the economic structure of the UK. Secondly, a range of environmentally adjusted forward and backward linkage coefficients has been developed, with a particular focus on coefficients adjusted for final demand, domestic extraction, publicly supplied and directly abstracted water, CO_2 emissions and NO_x emissions. Then the data on the final demand and environmentally adjusted forward and backward linkage coefficients were used in a multi-criteria 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 the others, using a panel of sustainability criteria, with final-demand-adjusted coefficients aimed at their maximum values and environmentally adjusted coefficients at their minimum values. The results show that the following sectors:

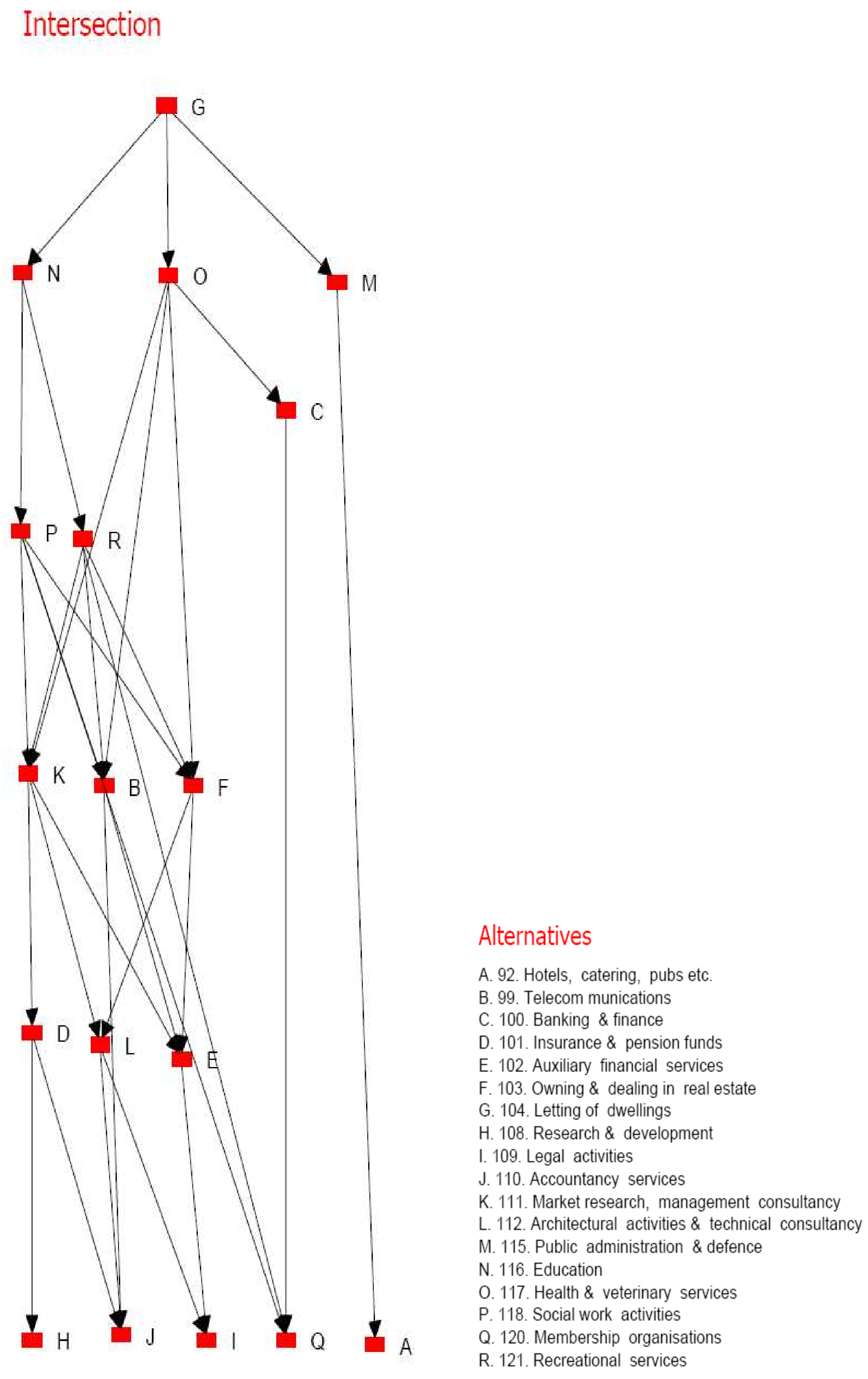
117 Health and Veterinary Services
104 Letting of Dwellings
116 Education
121 Recreational Services
101 Insurance and Pension Funds

118 Social Work Activities
99 Telecommunications

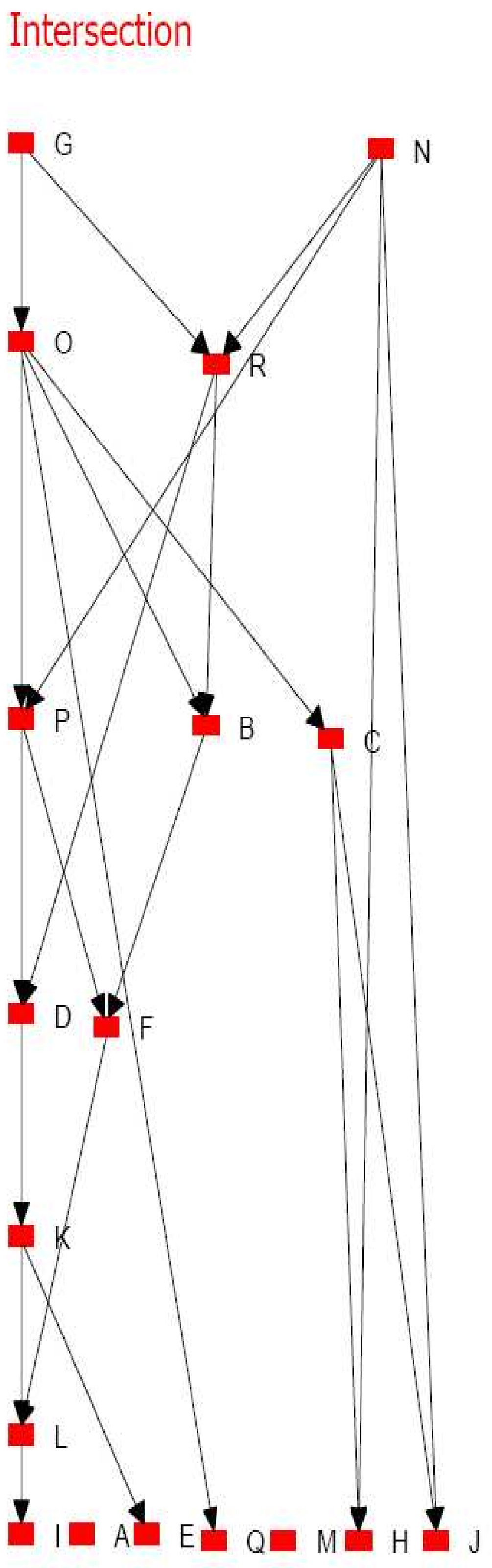
with relative stability appear within the top 10 most sustainable sectors of the UK economy, from the point of view of both direct and indirect effects, in the strong sustainability, weak sustainability, and neutral assessments.

The paper offers a justification for a substantial governmental investment programme which could not only 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 in our opinion presents a challenge and at the same time offers an opportunity for the reorientation of government investment priorities towards more sustainable industries. Unfortunately this particular aspect of the problem is not currently being discussed in the UK.

Annex 1. The most sustainable sectors, UK, 2002, α=0.1 - weak sustainability setting



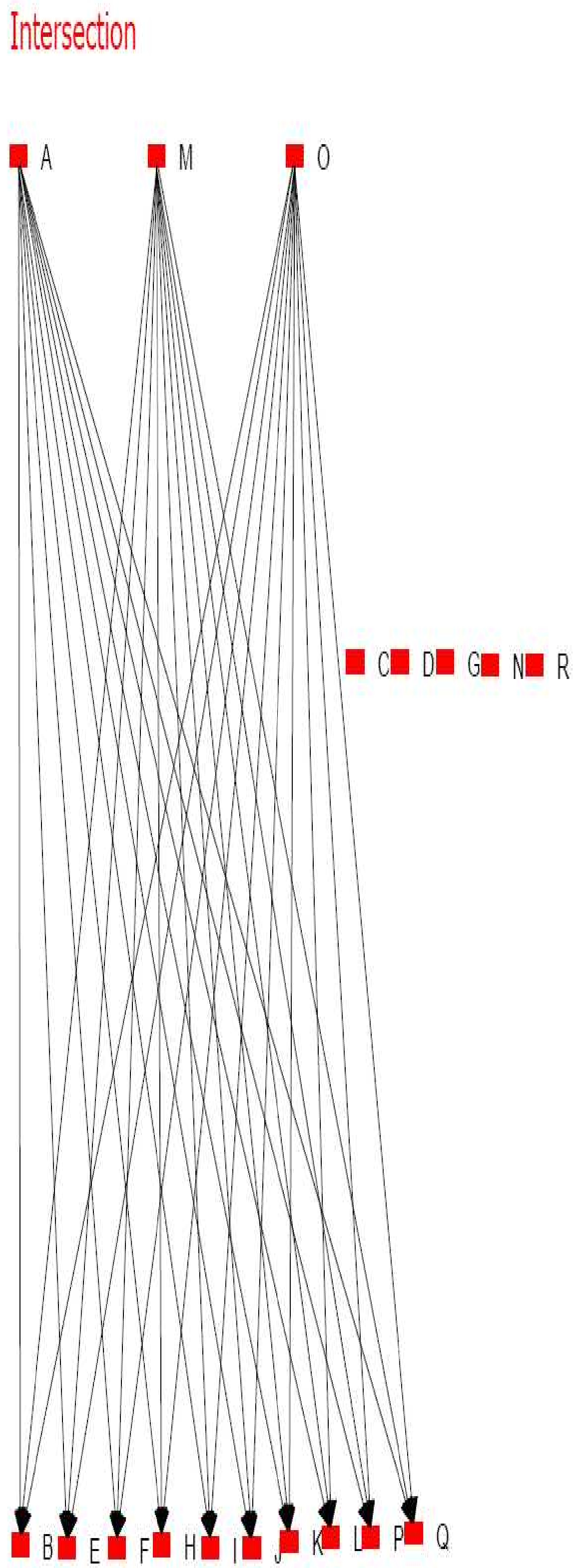
Annex 1. The most sustainable sectors, UK, 2002, α=0.5 - neutrality setting



Alternatives

A. 92. Hotels, catering, pubs etc.
B. 99. Telecom munications
C. 100. Banking & finance
D. 101. Insurance & pension funds
E. 102. Auxiliary financial services
F. 103. Owning & dealing in real estate
G. 104. Letting of dwellings
H. 108. Research & development
I. 109. Legal activities
J. 110. Accountancy services
K. 111. Market research, management consultancy
L. 112. Architectural activities & technical consultancy
M. 115. Public administration & defence
N. 116. Education
O. 117. Health & veterinary services
P. 118. Social work activities
Q. 120. Membership organisations
R. 121. Recreational services

Annex 1. α=0.9 - strong sustainability setting



Alternatives

A. 92. Hotels, catering, pubs etc.
B. 99. Telecom munications
C. 100. Banking & finance
D. 101. Insurance & pension funds
E. 102. Auxiliary financial services
F. 103. Owning & dealing in real estate
G. 104. Letting of dwellings
H. 108. Research & development
I. 109. Legal activities
J. 110. Accountancy services
K. 111. Market research, management consultancy
L. 112. Architectural activities & technical consultancy
M. 115. Public administration & defence
N. 116. Education
O. 117. Health & veterinary services
P. 118. Social work activities
Q. 120. Membership organisations
R. 121. Recreational services

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

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