UK Energy Research Centre

Funding a Low Carbon Energy System: a fairer approach? Summary of data and methods

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The Leontief input-output equation

Input-output models have been adopted by environmental economists due to their ability to make the link between the environmental impacts associated with production techniques and the consumers of products. The Leontief Input-Output model is constructed from observed economic data and shows the interrelationships between industries that consume goods (inputs) from other industries in the process of making their own products (outputs)[1].

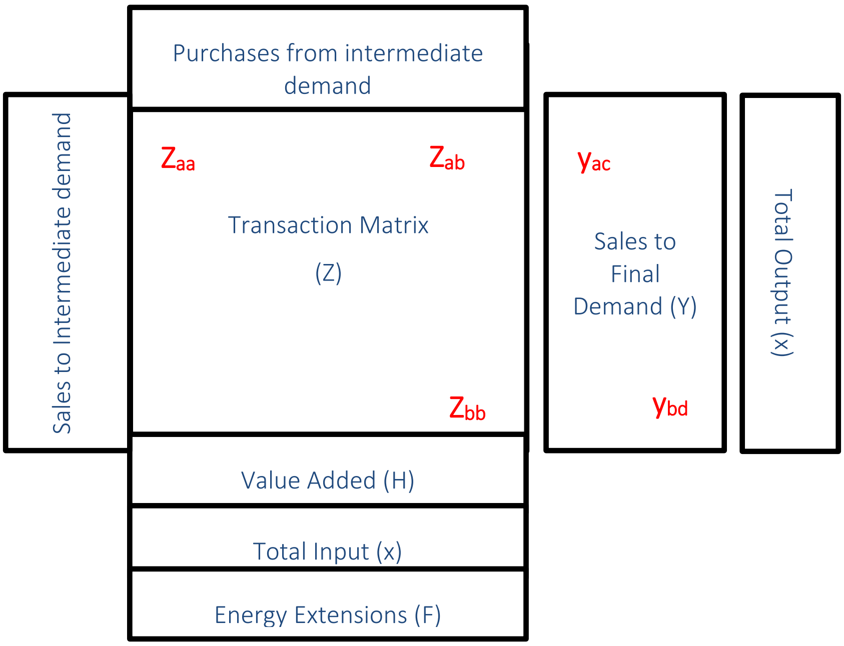

Figure 1: Basic structure of a Leontief Input-Output Model

[1] Miller, R. E., & Blair, P. D. (2009). *Input-output analysis: foundations and extensions*. Cambridge University Press

Consider the transaction matrix $\mathbf{Z}$ above; reading across a row reveals which industries a single industry sells to and reading down a column reveals who a single industry buys from. A single element, z_{ij}, within $\mathbf{Z}$, represents the contributions from the i^{th} sector to the j^{th} industry or sector in an economy. For example, z_{aa} represents the ferrous metal contribution in making ferrous metal products, z_{ab}, the ferrous metal contribution to car products and z_{bb} the car production used in making cars. Final demand is the spend on finished goods. For example y_{ac} is the spend on ferrous metal products by households as final consumers whereas y_{bd} is the spend on car products by government as final consumers.

The total output (x_i) of a particular sector can be expressed as:

$$x_{i=}z_{i1} + z_{i2} + \cdots + z_{ij} + y_i \qquad (1)$$

where y_i is the final demand for that product produced by the particular sector. If each element, z_{ij} along row i is divided by the output x_i , associated with the corresponding column j it is found in, then each element in $\mathbf{Z}$ can be replaced with:

$$a_{ij} = \frac{z_{ij}}{X_j} \qquad (2)$$

to form a new matrix $\mathbf{A}$.

Substituting for (2) in equation (1) forms:

$$x_{i=}a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{ij}x_i + y_i \qquad (3)$$

Which, if written in matrix notation is $= \mathbf{Ax} + \mathbf{y}$ *.* Solving for $\mathbf{y}$ gives:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{y} \qquad (4)$$

where $\mathbf{x}$ and $\mathbf{y}$ are vectors of total output and final demand, respectively, $\mathbf{I}$ is the identity matrix, and $\mathbf{A}$ is the technical coefficient matrix, which shows the inter-industry requirements. $(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}$ is known as the Leontief inverse (further identified as $\mathbf{L}$). It indicates the inter-industry requirements of the i^{th} sector to deliver a unit of output to final demand. Since the 1960s, the IO framework has been extended to account for increases in the pollution associated with industrial production due to a change in final demand.

Consider, a row vector $\mathbf{f}$ of annual energy used by each industrial sector:

$$\mathbf{e} = \ \mathbf{f}\hat{\mathbf{x}}^{-\mathbf{1}} \qquad (5)$$

is the coefficient vector representing energy per unit of output[2]. Multiplying both sides of (4) by $\mathbf{e}'$ gives:

$$\mathbf{e}'\mathbf{x} \ = \ \mathbf{e}'\mathbf{Ly} \qquad (6)$$

and simplifies to:

$$\mathbf{F} \ = \ \mathbf{e}'\mathbf{Ly} \qquad (7)$$

where $\mathbf{F}$ is the energy in matrix form allowing consumption based energy to be determined. $\mathbf{F}$ is calculated by pre-multiplying $\mathbf{L}$ by emissions per unit of output and post-multiplying by final demand. This calculation shows how a unit change in final demand $\mathbf{y}$, increases the energy used by all industries to satisfy this change.

[2] $\hat{}$ denotes matrix diagonalisation and $'$ denotes matrix transposition

This system can be expanded to the global scale by considering trade flows between every industry in the world rather than within a single country. This type of system requires a multiregional input–output (MRIO) table. The latest audits of the main global MRIO initiatives[3,4] describe six systems, of which three (WIOD, Eora and EXIOBASE) were released in 2012. The other MRIO systems available are GTAP, AIIOT and systems using OECD tables.

A UK multiregional input-output model

A UK energy footprint model needs to be able to measure the impact of UK consumption of products, taking into account domestic and foreign production supply chains. This means the MRIO table needs to have information about flows of products from abroad, to both UK intermediate demand and final demand. Production efficiencies vary between different producers, meaning that the impact per pound spent may be larger for a product from country A than from country B. The most accurate representation of the UK consumption-based energy account would need to measure the flow of products from every country and understand the energy intensities associated with each industry in every country. However, when we consider how the model may be used and practicalities such as model size, data storage capacity and model run times, aggregating trade partner countries is preferable.

The University of Leeds builds a UKMRIO database to calculate the UK's officially reported consumption-based account (CBA) for CO_2 and all other GHGs (Defra, 2016). By using the energy extension vector ($\mathbf{f}$) described above, this model can be extended to report the energy CBA. Since the CBA is a National Statistic[5], the MRIO database must be built using IO data produced by the UK's Office of National Statistics (ONS). The ONS produces Supply and Use tables (SUT) on an annual basis at a 106 sector disaggregation[6]. The use tables are combined use tables, meaning that the inter-industry transaction table is the sum of both domestic transactions and intermediate imports, and the final demand table shows the sum of both domestic and imported final products. On a 5-yearly basis, the ONS produces a set of analytical tables where the use table is domestic use only. Final demand is also split to show domestic purchases separately. Taking proportions of domestic spend versus imports from the analytical tables, we are able to extract domestic spend and data from the annual SUT tables. Imports to intermediate industry is now a single row of data and exports to intermediate and final demand is a single column of data.

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[3] Inomata, S., & Owen, A. (2014). Comparative Evaluation of MRIO Databases. *Economic Systems Research*, *26*(3), 239–244. doi:10.1080/09535314.2014.940856

[4] Peters, G. P., Andrew, R. M., & Lennox, J. (2011). Constructing an Environmentally-Extended Multi-Regional Input–Output Table Using the Gtap Database. *Economic Systems Research*, *23*(2), 131–152. doi:10.1080/09535314.2011.563234

[5] Defra (2016) https://www.gov.uk/government/statistics/uks-carbon-footprint

[6] ONS (2014) http://www.ons.gov.uk/ons/taxonomy/index.html?nscl=Supply+and+Use+Tables

Data from the EXIOBASE MRIO database[7,8] is used to disaggregate the import and export data to further sectors from other world regions. Data from EXIOBASE is also used to show how foreign sectors trade with each other, but first the data must be converted to Great Britain Pounds (GBP). The EXIOBASE MRIO database is mapped onto the UK's 106 sector aggregation. Once this step has been performed, the data can be further aggregated by region. Since EXIOBASE contains data from 49 countries and regions, we are able to select the most appropriate regional grouping for the trade data. For this MRIO study, we construct fourteen regions: the UK, Australia, China, India, Indonesia, Japan, Russia, Korea, North America, Central and South America, the Rest of the European Union, the Rest of Europe, The Middle East and the Rest of the World.

This model allows the calculation of the full supply chain energy use associated with final demand spend by UK households and Government.

Household expenditure data

The UKMRIO database contains information on how all UK households spend. For this study we need to disaggregate the household expenditure into spend by household income groups. To do this we use data from the Household Expenditure Survey table A6 which shows weekly expenditure by average households from each income deciles. We use this data to portion total UK household expenditure in the UKMRIO database. Household expenditure surveys use the United Nation's Classification of Individual Consumption According to Purpose (COICOP) system for collating spends[9]. Input-Output databases are generally organised by industrial classifications systems which are usually some level of grouping of the UN's International Standard Industrial Classification (ISIC) of All Economic Activities[10]. In order to find the consumption-based energy impact by income decile we translate household spends from COICOP product categories to ISIC industry categories. There is no standard concordance matrix for this and the mapping will vary from year to year, as differing quantities of certain products will map to a single industry, depending on how important they are in the consumption basket for that particular year.

The first step in splitting the UKMRIO household spend vector into ten income expenditure profiles is to understand how the product sectors in the UKMRIO database relate to COICOP sectors. First we map the 106 UKMRIO sectors to ISIC Rev 4. The next step is to map the ISIC Rev 4 to the United Nations Central Product Classification (CPC) (using correspondence data

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[7]Tukker, A., de Koning, A., Wood, R., Hawkins, T. R., Lutter, S., Acosta-Fernández, J., … Kuenen, J. (2013). Exiopol – Development and Illustrative Analyses of a Detailed Global MR EE SUT/IOT. *Economic Systems Research*, *25*(1), 50–70. doi:10.1080/09535314.2012.761952

[8] Wood, R., Stadler, K., Bulavskaya, T., Lutter, S., Giljum, S., Koning, A. De, … Tukker, A. (2015). Global Sustainability Accounting—Developing EXIOBASE for Multi-Regional Footprint Analysis. *Sustainability*, *7*, 138–163. doi:10.3390/su7010138

[9] UN (2017) https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=5

[10] UN (2017) https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27

from the UN[11]. Finally, we can map CPC to COICOP level 3 using a further correspondence table from the UN.

The mapping matrix sums the number of times that an individual COICOP level three sector maps to an individual UKMRIO sector. The final stage of the mapping replaces the summed numbers with a binary classification, producing a matrix where the rows are sectors from the UKMRIO and columns COICOP categories. However, this matrix cannot yet be used to translate the COICOP spends to the UKMRIO categories; the binary mapping must be replaced with weights for the cases where there is a 'one-to-many' type correspondence. An iterative balancing process, known as RAS is used to find a solution of weights such that the row sums preserve the UKMRIO household spends and the column sums preserve the *proportion* of spends by COICOP sectors and income groups. We are now able to use this new matrix of final demand spends to calculate the energy consumption-based account by income decile.

[11] UN (2017) https://unstats.un.org/unsd/cr/registry/regot.asp?Lg=1

Results tables

In this section we provide the data used to generate each of Figures 1 to 4.

Figure 1: Breakdown of policy costs (National Audit Office (2016). 'Controlling the consumer-funded costs of energy policies: The Levy Control Framework')

Description	2016 Cost (£bn)	2020 Cost (£bn)
Renewables Obligation: Requires energy suppliers to either meet targets for sourcing a set proportion of their energy from low-carbon generators, or pay a fee for any shortfall against this target into a 'buyout fund', which is redistributed among suppliers who meet the Obligation. The Obligation will close to new generating capacity on 1 April 2017.	3.8	5.2
Contracts for Difference (CfDs): The successor to the Renewables Obligation, CfDs are long-term contracts between energy generators and a government-owned company, which guarantee generators a set price per unit of electricity sold (the strike price). If wholesale prices of electricity are lower than the strike price, the difference is paid for by the government owned company and the costs of these 'top-up payments' are recouped from energy suppliers. Conversely, payments flow in the opposite direction when wholesale prices rise above the strike price. This stabilises revenues for the generator while protecting consumers from paying higher support prices when wholesale electricity prices are higher.	0.1	2.0
Feed-in Tariffs scheme: A scheme to support investment in small-scale low-carbon electricity projects, including domestic installations. Participants in the scheme are paid set tariffs for producing electricity. The tariffs offered to new participants have reduced over time, and there are now caps on the amount of capacity that can be supported in different technologies and size bands.	1.2	1.3
Warm Homes Discount: A scheme under which some households in receipt of benefits or Pension Guarantee Credit can apply for a reduction on their energy bill.	0.3	0.3
Capacity Market: A system for providing payments to new or existing power generators in exchange for guarantees that they will provide electricity generating capacity, even if it is not actually called on to provide power. In March 2016 the Office for Budget Responsibility forecast that payments in 2020-21 would reach £0.9 billion. Since then, the government has announced its intention to procure more capacity than previously planned, meaning annual costs are likely to be higher. The first payments will be made in 2017-18.	0.0	At least 0.9
The Energy Company Obligation: A regulation requiring the largest energy suppliers to install energy-efficiency measures in homes in order to cumulatively reduce CO2 emissions by a set amount. Suppliers face penalties if they do not comply.	0.8	0.6
Smart Meters Programme: A regulation requiring energy suppliers to take all reasonable steps to replace traditional gas and electricity meters in Great Britain with smart meters by 2020	0.3	0.2

Figure 1: Relationship between the energy system and energy service demands – the energy demand chain

	UK production energy (Mtoes)
Domestic heating and travel	49.22
Industry	34.91
Transport	28.24
Services	19.69
Electricity	68.90

Inter-industry transactions (Mtoes)	To industry	To transport	To services	To electricity
From industry	18.32	2.94	12.88	0.78
From transport	3.53	17.68	6.92	0.12
From services	2.32	0.65	16.60	0.12
From electricity	23.73	3.30	19.09	22.78
From imports	7.03	3.06	26.31	1.11

Exports	RoW intermediate and final demand (Mtoes)
From industry	21.72
From transport	7.46
From services	23.92
From electricity	0.65

UK final demand (Mtoes)	Home heat & power	Travel	Food	Consumables	Recreation & communication	Services	Government & capital
From industry	16.04	2.45	6.28	2.71	0.51	1.02	4.19
From transport	0.00	19.48	0.00	0.06	0.01	0.00	0.63
From services	0.00	1.90	5.00	5.85	6.13	5.57	33.43
From electricity	24.25	0.00	0.00	0.00	0.00	0.00	0.00
From domestic heating and travel	27.17	22.05	0.00	0.00	0.00	0.00	0.00
From direct Imports	0.62	13.05	5.97	15.08	3.21	1.76	8.72

Figure 2: Energy demand (tonnes of oil equivalent) by income decile and energy service (2014)

Decile	Home heat & power	Travel	Food	Consumables	Recreation & communication	Services	Imports	TOTAL
1	1.77	0.32	0.12	0.19	0.03	0.06	0.79	3.28
2	1.92	0.51	0.15	0.17	0.06	0.07	1.05	3.92
3	2.19	0.83	0.18	0.18	0.07	0.08	1.34	4.88
4	2.19	0.97	0.22	0.17	0.08	0.09	1.47	5.19
5	2.33	1.30	0.26	0.17	0.10	0.11	1.83	6.10
6	2.35	1.45	0.27	0.20	0.13	0.12	2.06	6.58
7	2.51	1.90	0.33	0.20	0.15	0.15	2.45	7.68
8	2.65	2.11	0.37	0.19	0.15	0.16	2.79	8.41
9	2.75	2.46	0.39	0.24	0.18	0.17	3.32	9.50
10	3.23	3.32	0.52	0.31	0.33	0.27	4.74	12.73

Calculated using the UKMRIO database and proportional shares based on the Household Expenditure Survey.

Figure 3: Alternative approaches to meeting energy policy costs and the proportion of household income required to meet the cost

Income decile	Annual income (£) (HES)	1. Household Bills (£)	2. Business Bills (£)	3. General taxation (£)
1	6,760	101.58	70.95	-
2	13,000	115.92	81.60	6.49
3	17,680	117.07	100.71	21.67
4	22,880	124.53	105.72	38.54
5	28,600	130.27	121.42	57.09
6	34,840	131.99	128.51	77.33
7	42,640	138.30	148.47	102.64
8	52,520	139.45	159.92	165.57
9	66,560	154.37	175.55	256.66
10	118,560	184.21	227.15	594.02

1) Calculated using distributional spend on heat and power by income decile from the Household Expenditure Survey (HES) adjusted to match the average cost of £132 for consumer funded energy policies.
2) Calculated by finding the share of the full consumption-based energy impact by each income decile and portioning the total consumer funded policy cost accordingly.
3) Portioning the total consumer funded policy cost by the share of total income tax paid by each income decile.