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2013/80/ISIC
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8th June 2013

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Characterizing an Economy by its Socio-Economic and Energy Activities

Investigating the structure and function of an economy in a resource-constrained world requires an understanding of the relationships of its fiscal, social, and environmental elements. We introduce a novel whole-economy analytical framework (the ‘4see framework’) which harmonises multiple national accounting procedures. The fiscal elements align with the international system of national accounts and the energy elements align with physical constraints. In a modular fashion, the 4see framework curates and maintains disparate accounts (economic stocks and flows, energy use, employment, transport) in parallel, but retains each of their unique measurement unit and accounting requirements. We present the UK as a case study to demonstrate how the data organisation and conditioning procedures are generic and will allow model development for other countries. The framework is capable of exploiting time-series ratios between different measurement units to give key functional relationships that vary gradually over time, are robust and thus useful for analysing national policy complexities such as decarbonisation, employment, investment and balance of payments. The 4see framework is neither an exclusively economic, physical or social model. It upholds the integrity of each world-view through retaining their unique time-series datasets. This has the potential to reduce tension between competing models and philosophies of economic development, societal change, environmental refurbishment, and climate change mitigation.

1. Introduction

Researching the possible economic, social and environmental impacts of choices made by fiscal and physical policymakers and planners is critical to improving the decision-making process (Leontief, 1993; Ayres, 2008; Baptist and Hepburn, 2013). We introduce an analytical method capable of assessing national investment capacity in technical infrastructure. The method addresses the systemic economic and biophysical (environmental and natural resource) implications of such investments, to complement current macro-economic modelling approaches.

Where conventional economic tools – which deal purely with abstract flows of money and the efficient allocation of capital – fail to provide important insights, an investigation of the relationships between economic volume flows and more fundamental entities such as material flows, infrastructure, and energy is required (Leontief et al., 1985; Pedersen and de Haan, 2006; Ayres and Warr, 2012). We argue that a purely economic approach needs to be coupled or reconciled with physical materiality to develop an understanding of the important constraints and opportunities they impose on an economy’s trajectory. For example, standard economic metrics may not consider properly exhaustible natural resources (Diaz and Harchaoui, 1997) and can lead to perverse subsidies (Baptist and Hepburn, 2013). Similarly failure to consider the important role of ecosystem services in the economic production process can lead to oversights and poor decision-making. We recognise the value of ecosystems services, but there is not as yet a consistent and satisfactory way in which to include ecosystems services in national accounts. However, Edens and Hein (2013) have made recent progress.

A previous difficulty of gathering time-series data is now being addressed, in part through ‘open’ Government and in part by modern information technology systems, enabling historic and contemporary data to be made readily available (ONS, 2012a, 2012b). Thus an empirical data-driven approach is now feasible. This frees the modeller from the constraints of equations derived solely from theoretical considerations. Mining data to test and propose robust relationships, and allowing changes in the structure of relationships over time, is a matter of asking relevant and tractable questions, which is at the heart of the approach we describe.

Although it is not commonly used outside of economics, the concept of ‘volume’ in national accounts follows from separating price inflation from value (Lequiller and Blades, 2006: 44). A standard economic approach considers the flow of money through a closed loop system initiated by household expenditure on goods and services provided by commercial and industrial activity, who in turn obtain intermediate commodities from other industries. The only independent inputs to the system are capital and labour.

In contrast a bio-physical approach considers the economic system to be open, with natural resource inputs (energy and materials) comprising the essential ‘free’ input required to produce and activate capital and maintain labour, as intermediates in the value-adding production process. As an open-system all energy and materials leave the system as low energy-high entropy wastes. The volume measure of products from national accounts is taken as a good proxy for quantifying the amount of these products (Lequiller and
Blades, 2006: 50; United Nations et al., 2009: 397). Jobs provided by industries are regarded as another necessary input in the process flow. The units for jobs are simply the number of employees at one time.

Taking the volume flows approach is to attempt a quantification of the capacity of an economy to function as well as to achieve major changes outside of the business-as-usual case. Examples include understanding the capacity of a nation to undertake (or respond to) military conflict, and to increase the standard of living for citizens. The motivation for our paper is to understand and consider the capacity, bottlenecks, and opportunities to undertake a transition to alternative economies, be they low-carbon, low-growth, full-employment, or based on entirely new industries.

In this paper we show how data, which are readily available in many nations, can be used to find some of the key determining factors affecting how the investment feedback from economic output operates. Although we use data for the UK as a case study, we consider this as a generally applicable method. We are taking a systems approach which helps to single out the strongest and most significant elements affecting economic activity—the principal characteristics. It important to note that (1) despite a heterodox approach to economic modelling and (2) the consideration of material/energy flows from a physical perspective rather than purely monetary, the analytical framework which we introduce is strictly aligned with the system of national accounts. This provides an important means of interpreting the effects using a language with which economists and the wider public are familiar.

1.1 The Structure of this Paper
This section spells out the key stages in the method which build-up the 4see analysis framework. The important point to make clear is the thread of how we make the problem tractable and simplify it sufficiently enough to yield a useful tool, yet one which remains powerful.

Section 2: demonstrates how the internationally accepted data and national accounting methods are exploited, and how they are conditioned to meet the needs of the research question.

Section 3: shows why, and justifies how, the large datasets are aggregated into physically meaningful groups and (data) flows. We show this for a single group (industry).

Section 4: expands this to all economic sectors, adding in the flows and relationships between industries. This is done in two steps to aid understanding.

Section 5: populates the skeleton with data for all sectors for a single year to show how the data can be visualised.

Sections 6 and 7: exploit the historical data to show useful ratios which naturally emerge from the analytical framework, and how this can be used to make physically justifiable projections.

The final section draws together our conclusions and suggests how this framework will be operationalized in a dynamic model.

2. Data Sources
The 4see framework is entirely data-driven. The concept of mapping the flows of economic outputs, energy, jobs and transportation through and around an economy requires knowledge of national accounts together with national statistics for employment, energy and transportation. The approach here is data driven using the best data wherever available. Being data-driven means that the framework must adapt to how the data is structured.

The natural source of economic data is national accounts. The System of National Accounts (SNA; United Nations et al., 2009) is the internationally agreed standard set of recommendations on how to compile measures of economic activity in accordance with strict accounting conventions based on economic principles. The recommendations are expressed in terms of a set of concepts, definitions, classifications and accounting rules that comprise the internationally agreed standard for measuring such items as GDP. The accounting terms we use conform with the SNA. The mapping of dynamic economic and biophysical flows and relationships to the existing structure of national accounts is a unique strength of the 4see framework.

Companies and organisations that have the same principal activity are grouped into industries. The SNA uses the International Standard Industrial Classification (ISIC, United Nations 2008a) to identify groupings. For transactions in goods and services in detail, the SNA uses the Central Product Classification (CPC, United Nations 2008b). The CPC is a classification based on the physical characteristics of goods or on the nature of the services rendered, while the ISIC also takes into account the inputs in the production process and the technology used by the production process. The definition of expenditure (final demand) by
type of consumption follows SNA. Time-series data can be built up from annual Supply and Use Tables (SUTs) that give a comprehensive view of the components making up GDP.¹

2.1 Data Conditioning
Most data are available annually and grouped by kind of activity according to ISIC or its equivalent. The Gross Value Added (GVA) data are available for the UK over the period 1990-2010; for 2003-2010 directly from input-output tables (ONS, 2012c) and for 1990-2002 extracted from the annual editions of ‘The Blue Book’² (ONS, 2012b). However the industrial classification was changed in 2011 and backdated to 1997. Data prior to 1997 have been scaled to give continuity. Supply and Use Tables are not available for 1990-1991. These years have been extrapolated back from 1992 and scaled to sum to GDP for those years.

Investments in assets which last longer than one year are referred to as – variously – ‘fixed assets’, ‘capital stocks’, and ‘fixed capital’. We use Fixed Capital (FC) throughout. Data for the Gross Fixed Capital Formation (GFCF) – the Fixed Capital Formation (FCF) total requirement – are published for all years. However, the FCF components by each industry were not published for 2010 at the time of writing. The data has been extrapolated from 2009 and scaled for the sum to equal to the total for 2010.

The 4see analysis framework depends on using metrics that are independent of time, therefore we have applied the GDP deflator across all economic measures – except for fixed capital. We make an exception for the formation of fixed capital (FCF) because 4see handles fixed capital separately from economic flows, and we assume stocks of fixed capital to be an effective proxy measure for their size.³

3. Methodology
Structuring the relationships of the flows to make the problem tractable is complex. This section explains the way we have aggregated the flows described in the resulting sections.

3.1 Level of Aggregation
Some industries are larger than others (by many metrics) and need to be distilled out from the complete dataset. By the same token, smaller entities can be aggregated together. This enables us to analyse the static relationships within the UK economy. We aggregate the list of industries under ISIC down to seven:

- agriculture, forestry and fishing (‘agriculture’), ISIC section A,
- mining and quarrying (‘extractive industries’), ISIC section B,
- supply of electricity, gas and water supply and water remediation services (‘utilities’), ISIC sections C and D,
- manufacturing, ISIC section C,
- construction, ISIC section F, and
- services, ISIC sections G to U.

Dwellings contribute to the economy by virtue of rental. They form the seventh category, though not technically an industry:

- dwellings, CPC class 7211.

3.2 The Functioning Entity of One Industry
Our premise is that production cannot proceed unless infrastructure first exists, thus we characterise the economy by considering its fixed capital that make up the physical infrastructure. From a system point of view, infrastructure takes time to grow and establish, thus setting a ceiling in the short term to constrain

¹ From SNA (United Nations 2008a) 1.24 ‘…the central framework of the SNA also contains detailed supply and use tables in the form of matrices that record how supplies of different kinds of goods and services originate from domestic industries and imports and how those supplies are allocated between various intermediate or final uses, including exports. These tables involve the compilation of a set of integrated production and generation of income accounts for industries by drawing upon detailed data from industrial censuses or surveys. The supply and use tables provide an accounting framework within which the product flow method of compiling national accounts, whereby the total supplies and uses of individual types of goods and services have to be balanced with each other, can be systematically exploited. The supply and use tables also provide the basic information for the derivation of detailed input-output tables that may be used for purposes of economic analysis and projections’.

² The 1990 edition is not available on-line at the present time.

production. Fixed capital giving rise to production – grouped by type of activity – are called industries; examples are power stations under the utilities industry, factories under the manufacturing industry, and commercial offices, schools and hospitals under the services industry. Dwellings are also fixed capital, but are not regarded as part of industry.

A schematic of the important flows related to fixed capital is illustrated in Figure 1. We quantify these flows in the most relevant way while accepting that the type of measurements (of flows) are only proxies for real flows. The only stock of output is products used for fixed capital formation (FCF) – this total output being GFCF. All other outputs are consumed within one accounting year. All industries have an economic output (by definition) which is their production. The sum of production over all industries in an economy (the gross value added) is one form of the GDP of the economy.

The fixed capital for one industry consists of a large number of establishments at various ages, and can be quantified by its replacement cost. Over a year, say, the fixed capital will decrease as a result of physical deterioration or normal obsolescence, which is referred to as Consumption of Fixed Capital (CFC). Thus we can think of the fixed capital that goes to make up an industry as having an average lifetime. The fixed capital for one industry is constantly being replenished by investment, referred to as Fixed Capital Formation (FCF). When the level of formation equals the level of consumption the size of the industry is constant. This is an example of stocks and flows, since FCF, FCF, and CFC all use the same units, though formation and consumption include the denominator of time. To complete this picture of one industry, we consider its inputs necessary for production. The primary inputs are energy (as fossil fuels or electricity) and jobs – each are accounted for and tracked separately within the framework. This modularisation of data streams within 4see allows for new datasets to be added, or for further disaggregation of those already included. In this way, data on the volume flows of raw materials and water also could be included explicitly.

At present, raw materials and water are implicitly accounted for by the energy required for their processing and their monetary value. Goods and services used in the course of production – intermediate consumption – are provided by other industries.

Each of the concepts in Figure 1 is quantified. The choice of units (Box 1) is important, and is discussed below. Note though that units of inputs and outputs are all different. In contrast to stocks and flows of the fixed assets, process flows describe inputs being converted to output.

3.3 Economic Volume Flows

The primary objective of the SNA is not simply to provide guidelines on measures of changes in prices and volumes but to assemble a set of interdependent measures that make it possible to carry out systematic and detailed analyses of inflation and economic growth (United Nations et al., 2009). To this end, an important and valuable feature of national accounts is their concept of ‘volume’ for products. The accounts are constructed in price-independent volume terms. Volume measures are derived from total expenditure on a product by applying a price or deflator index. While price indices are derived for many sub-sets of products, we use the single over-arching GDP deflator (except for fixed capital and the point at which FCF changes fixed capital). This weights the individual deflators according to their contribution to GDP.

4 The term depreciation is often used in place of CFC, but it is avoided in the SNA. This is because in commercial accounting the term depreciation is often used in the context of writing off historic costs whereas in the SNA CFC is dependent on the current value of the asset.
We take the volume concept in national accounts as a proxy measure of quantifying some of the flows in which we are interested. The measure of GDP easiest to express in volume terms is that of expenditure. The estimates of household consumption, capital formation, exports and imports can be deflated without much conceptual difficulty.

In using the volume measure for economic flows of products, we take the view of equivalence between domestic production and imports. We do not seek to distinguish the destinations for imported or domestic products. We recognise that if there is a radical change in the exchange rate, then our application of an economy-wide single deflator would mean the volume measure of imports would change. However the products themselves haven't changed so our proxy representation would be weakened. Rather than complicating our approach by applying a myriad of different deflators and maintaining separate accounts, we note that the GB economy has experienced a sufficiently stable exchange rate over the historical period to justify our use of a single deflator.

### 3.4 Dwellings

The SNA states that dwellings are goods used by their owners to produce housing services. Dwellings are a major class of fixed assets, for which data is available, but appear to have a low significance as an industry. The assets are found in the ISIC list under section L (of the services industry) class 6810 ‘real estate activities with own or leased property’. As a product, rental from dwellings appears under CPC as subclass 72111 ‘rental or leasing services involving own or leased residential property’.

National accounts measure what takes place in the economy, between which agents, and for what purpose. Given that the GDP of a country is viewed as an aggregate measure of production, the GDP measure would have an arbitrary component depending on the proportion of dwellings that are owner-occupied, yet the total of housing services provided is constant. To correct this otherwise arbitrary aspect, the SNA specifies that an imputed rental on owner-occupied housing, estimated from comparable properties in the rental market, is included in the production boundary and forms part of household consumption. We separate actual and imputed rental from the services industry and associate this total with the nominal industry of dwellings.

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5 Price indices for services are more difficult to compile than for goods. The SNA notes that research work is actively in progress to derive volume estimates of output of services that take account of changes in their quality.

6 United Kingdom national accounts use the UK Standard Industrial Classification (2007) system (ONS, 2009). Accordingly, the numerical coding 68.2 covers the actual expenditure on ‘Renting and operating of own or leased real estate’, but since there is no code for imputed contribution to GDP, the national accounts have created the label ‘68.2IMP’.
3.5 Energy
For energy, a better proxy for measurement of the flows is their energy units because these relate directly to the role of energy within the production process. However care must be taken when considering a mixture of energy and economic units of measures. We retain the economic volume flows along with energy flows despite evidence to suggest that the economic importance of energy, as represented by its share in the national accounts, is an underestimation (Ayres and Warr, 2009). Although the economic volumes are small, they are necessary for completing the sum of the GDP indicator.

Energy involves some specific infrastructure which has large enough fixed assets to warrant separate consideration outside of its overall industry. This infrastructure is generation plant for electricity (within the utilities industry) and refineries of crude oil to petroleum products (within the manufacturing industry).

3.6 Transportation
Transportation has significant fixed capital and energy use. Although the CPC for products identifies transport services, transportation is wider than this definition. Leasing services falls within the services industry, but includes vehicles which are leased to different industries. Data for fixed capital of all industries identify transportation separately from the fixed capital of buildings and the assets within them of plant and machinery. However the contribution of their transportation to the production process within the industry is not identified separately. Vehicles owned by households are not deemed to have an economic role. We segregate all transportation (Section 5.4). Transportation assets are in the middle of a process that converts fuel to the output of vehicles that travel a distance (measured as vehicle-km per year or passenger-km per year, DFT, 2013).

3.7 Jobs and GVA
Gross Value Added (GVA) is the costs of labour and capital to the producers that make up that industry. In Figure 1, the volume measure of the output is the sum of intermediate consumption plus value added by the industries production process, its GVA.

Showing jobs as an input in Figure 1 might be taken as double counting, but it is not. We need to make clear the distinction between a purely economic analysis and the physical flows approach. In the practical calculation of GDP, equality is presumed between the forms of GDP (income, output and expenditure). Compilation and reconciliation of SUTs is an important part of arriving at an accurate GDP value. This method is transferable between economies enabling trust and acceptance of the GDP figures. However the expenditure form is unique in its link to products and thus its use as a deflator. The expenditure form of GDP is taken as being the proxy for goods and services. This proxy is followed back up the production process so it is also a good proxy for industries and equated to GVA.

4. Considering the Whole Economy
The industry shown in Figure 1 is one part of an economy. The whole economy consists of all industries, which are dependent on each other as well sharing inputs and contributing to final outputs (goods and services). For clarity in understanding we will examine the (generalised) intermediate steps which comprise our analysis framework.

Consider an economy made up of three industries (Figure 2). This view introduces the concept of the system boundary, which is taken to be the geographic and trading border of the country, as in the scope of GDP. By including the trading border, we can introduce imports and exports of products (goods and services).

Whereas Figure 1 is straightforward in that inputs lead to a single product type, the intermediate consumption, which is between industries is more complicated. The approach to intermediate consumption in Figure 2 is to pull each industry apart, indicated by the broken borders for the sides for each pair of boxes that face each other. What emerges from the left-hand set of boxes is their own production (GVA). Also shown on the left are imports as if passing unprocessed behind the left boxes before adding to production. In the space between the pairs of boxes, industries provide some of their outputs to become others’ inputs. Although intermediate consumption is represented here as progressing from left to right, the interaction of imports, GVA, and intermediate consumption is mixed up in a myriad of sequences of real processes within the economy.

More precisely, GVA equals compensation of employees, plus gross operating surplus, plus taxes on production, less subsidies on production.
The main message to take from the schematic is that all products eventually emerge as final supply on the right with just three destinations:

1. Final consumption within the economy – consists of products used by individual households or the community to satisfy their needs.
2. Exports of products go outside of the system to intermediate or final consumption in other economies.
3. Fixed capital formation of the assets within the economy.

In following a given product from left to right in Figure 2, it clearly takes on a different form after the stage of intermediate consumption. At the point of production (or GVA) basic prices are the amount received by the producer from the purchaser for a unit of a good or service produced as output. At the point of final supply, the units change to purchasers’ prices. These are the amounts paid by the purchasers so are the actual costs to the users. The differences between basic and purchasers’ prices will become clear further on when specific data for the UK is introduced. We can recall at this point two of the ways of viewing GDP. The expenditure form of GDP refers to expenditure by households, so is at the point of final supply in Figure 2. The expenditure form of GDP includes net exports, corresponding to exports minus imports. The output form of GDP is a different way of viewing the economy. It corresponds to the total of GVA by each industry.

Figure 2 also shows energy in this hypothetical economy. The energy supply is made up of domestic production (emanating from within the system boundary) together with net imports.

4.1 SNA Nomenclature for Sectors and Transactions
Our use of the terms ‘sector’ and ‘transaction’ complies with SNA. The whole economy (code S1) is divided into five mutually exclusive sectors S11 to S15 (Figure 3(a)) and listed in Figure 5. The fundamental units identified (United Nations et al., 2009: 75) are the economic units that can engage in the full range of transactions and are capable of owning assets and incurring liabilities on their own behalf. These units are called institutional units. They are grouped together to form five institutional sectors, on the basis of their principal functions, behaviour and objectives. Together, S11 and S12 are sometimes known as market and loosely referred to as enterprise. Sectors S15 and S13 are sometimes known as non-market or social. Their comparative economic activities are shown in Figure 3(b). Transactions in the SNA are exchanges of economic value between institutional units (United Nations et al., 2009: 76). The SNA lists seven, by P codes (Figure 3(c)). P3 is final consumption expenditure by households. Households also benefit from the sectors S15 and S13, but their funding is indirect, through general taxation, so this is part of actual final consumption, P4.

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8 More accurately, basic prices are minus any tax payable on products, and plus any subsidy receivable on products.
5. Data for One Year

Developing Figure 2, we can construct a complete dependency diagram for a whole economy, using the UK as an example. To compare levels of activity, an appropriate representation is as a Sankey diagram, where the widths of lines are proportional to size of flow, and functional separation into different product streams (Kennedy and Sankey, 1898). These are frequently used in energy and material flow studies (Schmidt, 2008) and recently for energy flows in shipping (Baldi et al., 2012). Commonly, Sankey diagrams use the same units throughout (or have a point of conversion). We introduce a novel aspect by merging economic and physical flows – and data with different units of measurement – into a single representation which can be interrogated to reveal meaningful relationships which better reflect the structure and nature of an economy.
Figure 4 is a Sankey diagram of the flows for the UK economy for 2010. We describe the principal Sankey elements below, and introduce some of the possible numerical analyses in section six.

5.1 Basis of Aggregation
Looking at the economy as a whole in Figure 4, we can see the justification for the level of aggregation chosen. There is the expected division of goods and services. Inputs to their industries of manufacturing and service are very different: manufacturing is a high user of energy and services are the largest employer.

The separation of the construction and dwellings industries is unusual, but has important advantages. Contrasting the features of construction with manufacturing and service, the key features are that construction’s main destination from final supply is to gross fixed capital formation (GFCF), it is a large employer, and it has no imports or exports. Dwellings are a significant user of energy which is accurately shown as associated with being a producer of rental (housing services). However, dwellings do not provide any employment. By separating rental from the output of the services industry means that services better reflects the flow resulting from the fixed capital and inputs to the services industries.

5.2 Assets
All of the fixed capital of all industries and dwellings are represented by boxes in Figure 4, as in Figures 1 and 2, though the size of the boxes has no significance in this diagram. Each box has a blue line for FCF. Compared to the introduction of flows in Figure 1, consumption of fixed capital, CFC, is not shown but is taken as being implicit for all the boxes that represent fixed capital.

The three smaller industries of agriculture, extraction, and utilities are all shown at the top with their fixed capital formation entering their bottom edges. For the extractive industries, the fixed capital is responsible for the domestic extraction of crude oil, coal and gas. Their origination is shown on the left. For the utilities industries, this is split between power generation on the left and the rest of this industry is at the top.

5.3 Economic Volume Flows
In terms of the contribution to GDP, Figure 4 shows that the highest GVA for the UK economy are the three larger industries and dwellings. Their associated outputs are called:

- Goods from manufacturing, CPC groups 2-4.
- Construction services, CPC group 5.
- Services, CPC groups 6-9.
- Actual and imputed rental from dwellings, CPC class 7211.

Due to their dominance, we only need to consider the intermediate consumption for manufacturing, construction, and services. The three smaller industries and their products, only net intermediate consumption to the three larger is considered, which is justified by their small net intermediate and final volumes in Figure 4. One additional line is required. The SNA picks out ”transport and trade margins” (also known as distributors’ trading margins) which we treat as a special case of intermediate consumption of the services industry (mostly going to manufacturing). Data is separately itemised for this in national accounts. It makes a significant difference between goods at basic prices, from import or production, to goods at purchasers’ prices for final supply. Another point to make about purchasers’ prices (on the right) is that it includes net taxes (less any subsidies) on products. Since these taxes increase the proxy measure of the volume of goods, they are shown in the Sankey format as increasing the line width.

Although Figure 2 shows a part of final demand within the economy as benefitting the population, national accounts distinguish between purchases made by households and services from Non-Profit Institutions Serving Households (NPISH) and Government. NPISH include foundations, membership organizations, religious organizations, and trade unions, which are funded indirectly. Government services are provided to the community or to individual households but are also paid for indirectly, being financed through taxation and other forms of Government income.

Figure 5 shows how the economic aspects of Figure 4 relate to the S- and P-codes in Figure 3. All the boxes in Figure 4 relate to the S-codes for sectors.

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9 Fixed capital within households, such as white goods, is not included in national accounts.
Figure 4. A high-level Sankey diagram of the relationships between industries shown here for energy, jobs and economic volumes flows with data for the UK economy in 2010. All fixed capital within the economy is represented by boxes (there is no significance to their dimensions.) All horizontal Sankey lines are flows from left to right with the sole exception of ‘investment’, which flows back from right to left. Each fixed-capital processes transforms inputs into outputs (from left to right). Fixed capital is increased in size by investment (blue lines). The investment line is not shown either for ‘refining’ (part of manufacturing) or for ‘electricity’ (part of ‘utilities’). Domestic production by industries (GVA) is shown by Sankey lines that start broken and emerge solid. These lines change width for the manufacturing and services industries to represent the change from GVA specified by industry groupings, to output specified by product groupings. NPISH is non-profit institutions serving households.
Figure 5. Overlay of the economic flows and infrastructure of Figure 4 with the S- and P-codes of Figure 3.

Figure 6. A Sankey diagram to show detail of energy use by UK transport using data for 2010. Volume flows of energy (on the left) are used to create ‘mobility’ (on the right). The choice of measure for travel is mainly determined by availability of robust data. (LGV: light goods vehicle. HGV: heavy goods vehicle.)
5.4 Transport
From an energy perspective, all transportation is brought together at one point in Figure 4. Greater detail is given in Figure 6. The fixed capital in Figure 6 are grouped by their use for either passengers or freight transport. The change in capital, through FCF and CFC, is not shown. Inputs to transportation are petroleum products and electricity.

Outputs shown on the right are selected according to relevance and the availability of robust data. For instance, the annual motor test ensures an accurate record of total travel of the entire car fleet. Thus the output for cars is vehicle-km/y whereas actual occupancy data is more difficult to gather. In the case of road freight, data of tonne-km/y is collected for trucks (heavy goods vehicles, HGV) but not for vans (light goods vehicles, LGV).

5.5 Population and Jobs
The connection between jobs in Figure 4 and the whole population of the country is shown in Figure 7. In contrast to our other Sankey diagrams, all the quantities in Figure 7 are stocks or status measures; none are flows with per-year units.

The logical starting point is population. To the left, the population is grouped into households which the SNA define as the consuming unit (on the right in Figure 4). Further to the left, households reside in dwellings, corresponding to the dwellings industry at the bottom of Figure 4. From population going to the right, the divisions are first by age, followed by whether economically active for the labour force. There is then a change of unit to ‘jobs’, which is the data reported by the industries as the employers (ONS, 2013). The industry groupings at the top right is as shown in Figure 4.

The National Travel Survey (DFT, 2012: Table NTS0906) shows the average car occupancy in the range 1.56 to 1.60 for every year over the period 1995 to 2010.
5.6 Balance of Payments

Balance of payments concern the parts of the Sankey diagram in Figure 4 which change from volume to monetary flows. The concepts for an economy introduced so far have all been about the innate quantities, whether goods, services, energy, or people doing jobs. Within the system boundary of a national economy, the interaction of all these, though mediated by money, is constrained by the sorts of relationships summarised in Figure 4. The balance of payments is shown in Figure 8 with the transactions divided into trade and non-trade. The relationships of the transactions within the formal presentation of capital, current, and financial accounts (IMF, 2011) is shown in Table 1.

Table 1. Categorisation of the flows in the UK balance of payments. To be read in conjunction with Figure 8.

<table>
<thead>
<tr>
<th>Category</th>
<th>Transaction Type</th>
<th>Account Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trade</td>
<td>Imports</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>Exports</td>
<td>Current</td>
</tr>
<tr>
<td>Non-trade</td>
<td>Assets (change in ownership)</td>
<td>Investments</td>
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<tr>
<td></td>
<td></td>
<td>Debt securities</td>
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<tr>
<td></td>
<td>Assets (income from)</td>
<td>Investments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Debt securities</td>
</tr>
<tr>
<td>Intrabank transfers</td>
<td>Other investments</td>
<td>Financial</td>
</tr>
<tr>
<td>Residual</td>
<td>Transfers</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>Reserve earnings</td>
<td>Current</td>
</tr>
<tr>
<td></td>
<td>Reserve assets</td>
<td>Financial</td>
</tr>
</tbody>
</table>

Trade

The current account covers transactions that do not give rise to future claims and includes all of trade. Comparing Figures 4 and 8, the left- and right-hand sides are complementary. An inward flow of imports on the left in Figure 4 is matched by an outward flow of funds (to the left) in Figure 8. On the right hand side, exports in Figure 4 are matched by funds flowing in Figure 8. One exception in the case of the UK (in our example year of 2010) is that while the net volume flow of petroleum products in energy terms is an export on the right in Figure 4, in monetary terms the net flow is as an import on the left in Figure 8 (DECC, 2012; ONS, 2012a, 2012b). This results from differential pricing of the particular petroleum products traded.

Non-trade

Non-trade transactions consist of the remaining items in the current account together with all items in the capital and financial accounts (ONS, 2012a). As in the earlier Sankey diagrams, boxes represent fixed capital, but the focus is on their geographical location and ownership (not type of activity). Boxes also represent debt securities, consisting mostly of bonds, which have no specific connection to any particular fixed capital. Transactions on the bottom of the boxes for both fixed assets and debt securities correspond to purchases for an inward flow and sales for an outward flow. Transactions on their sides are always outward representing income dividends or interest.

Two non-trade transactions of ‘other investments’ and ‘reserves’ are shown as net flows which can change from inward to outward from year to year. ‘Other investments’ are mainly intrabank transactions across national borders. If these were to be shown as gross flows they would dwarf other non-trade flows, but are more meaningful when shown as net. Flows for reserves in the financial accounts for the UK are only shown as net.

Constraint of balance of payments

The balance of payments includes imports, which from a systemic point of view in the 4see framework, offers two advantages and one constraint. The first advantage is that imports are flexible, as long as there is
the foreign exchange for their purchase. The second is that through money, any sort of export can be ‘converted’ into an import (cash). But the overriding constraint of the balance of payments is that it should balance, as emphasised by how the national inward and outward flows are brought together in the centre for direct comparison.

6. Temporal Variations

Each entity within the Sankey diagrams has time-series data associated with it, even though the diagram itself visualises the complete dataset only for a single year. Equally important is visualising temporal changes. We take as our starting year 1990. This is a compromise between the availability of the wide range of data that we require and our desire for a balance of the historical perspective with the projection into the future. Prior to about 1990, historical data becomes less complete, categories change, and data collection and processing methodologies pre-date significant recent alterations. For example, SUTs (Supply and Use Tables) for the UK economy are not available before 1992. We give a small number of examples of the raw data flows and how our framework allows for the data to be systematically exploited in a straight-forward manner. This is the first step in operationalizing the 4see framework.

Time-series data for fixed capital and output, Figures 9(a) and 9(b), show behaviour for the 21-year period since 1990 for the services industry (ONS, 2010). Both volume output and fixed capital have increased steadily while the volume output shows a slight decrease for the last three years of 2008-2010. Figure 9(c) shows the ratio between these two quantities, which is the economic output compared to physical assets. This is similar to the concept of return on capital. Since 1995 this ratio has been declining steadily.
Figure 9. Examples of temporal data for the UK services industry over the period 1990-2010. (a) Annual production (GVA), (b) size of fixed capital, (c) ratio of production to size of asset.

Figure 10. Examples of temporal data for two inputs needed by the UK services industry over the period 1990-2010. Data for the services industry production in Figure 9(a) is used to calculate the ratios: (a) Annual use of thermal energy (mostly gas), (b) ratio of thermal energy to production, (c) need for jobs, and (d) ratio of jobs to production.
Two of the inputs used by the services industry (ONS, 2012b) are shown in Figure 10. Thermal energy in Figure 10(a) is made up of solid fuel, heating oil and gas. Their proportions in 1990 were 8%, 27% and 65% evolving by 2010 to just oil and gas at 11% and 89% respectively (DECC, 2012). Total consumption has been decreasing over the historical period. Figure 10(b) shows the amount used per unit volume output of Figure 10(a). Fitting an exponential decay to the steady decline since 1995 suggests approach at -3.5%/y to an asymptote at 16% of the 1995 level. The trend of employment in the services industry in Figure 10(c) is shown as mostly increasing (ONS, 2011). However when taken as a ratio with volume output of Figure 10(a), the trend has mostly been downward over the historical period. Fitting an exponential decay to the steady decline suggests approach at -3.0%/y to an asymptote at 54% of the 1990 level. In 1995 and 1996, there was a temporary slowing of the decline, but the ratio appears to have returned to the overall decay trend. The data deviates in 2008 and the question is whether this signals an end to the decay or whether there will be a later return to the trend line, as there was in 1997.

7. Relationships Between Flows
At this point we depart from analysing and visualising structural connections in the economy and time-series data, and turn to predictive relationships. The ratios in Figure 9(c), 10(b), and 10(d) can be added to the format of Figure 1. For the services industry, this is shown in Figure 11 with the ratios represented by the dashed arrows. The direction of these dashed arrows is the first step of operationalizing the 4see framework into a model. The bowtie symbols on the flows in Figure 11 – like mechanical valves – represent regulators of the flow.

We have established that the stock of fixed capital has a lifetime. This means, according to the format of Figure 11, that the value of fixed capital when divided by the lifetime gives the value of CFC. When introducing one industry in Figure 1, we assumed that fixed capital must be in place before production is possible. In Figure 11 we can consider production as linearly dependant on the size of the fixed capital by a constant of proportionality. Finally if we consider all the inputs as being linearly dependant on production, each input would have its own constant of proportionality. Most of these relationships are between mixed measurement units. For example, if production is in £million[1990]/y and consumption of electricity in TWh/y, then the constant of proportionality of electricity needed per unit of production would be TWh/£million[1990].

![Diagram](image.png)

**Figure 11.** In this example schematic, the services industry is developed from the general case set out in Figure 1. It shows the dependencies (dashed lines) used in the 4see framework between flows and the fixed capital of the example industry. Flow of CFC is related to fixed capital by the lifetime of fixed capital. Production is dependent on fixed capital, with the time-varying constant of proportionality calibrated by taking the ratio of historical production to historical fixed capital. Similarly, each of the inputs is separately dependent on production with their own constants of proportionality calibrated from historical data (the origin of the input flows is shown in Figure 4). The dependency for FCF is not shown in this schematic.

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11 We understand model to mean a computational mode: a specification of an executable representation of an observable system, which can be used to both explain and explore the dynamics and possible future trajectories of the system.
8. Conclusions
The 4see framework has its roots in a large set of computational frameworks developed over the last 30 years ranging from purely physical to purely economic – straddling the two principal philosophies. What makes 4see different is its embrace of the important tenets of policy credibility. It is compatible with the international SNA and its key whole-economy indicators, such as GDP, maintaining the lingua-Franca of policy discourse. Further, it introduces a method of physically meaningful visualisation based on Sankey diagrams. Using this framework, it is possible to find systematically sets of relationships within an economy which are key determining factors affecting investment (GFCF) resulting from economic output. There is considerable scope for using the 4see framework for mining the UK data, and for further enriching the dataset. A useful development will be to separately account for the volume flows of water and raw materials (such as steel, aluminium, aggregates, and cement). An obvious next step is to create datasets for other nations. The inclusion of data for water would then be very important for a nation such as Singapore. The key piece of future work, however, is to operationalize the framework into a dynamic model to enable policy options and scenarios to be examined.

Using the UK as a case study of how the 4see framework can be exploited, we can make observations about the services industry since 1990. First, economic output compared to physical assets (return on capital) has been declining steadily; and second, economic output compared with both the amount of thermal energy and the number of jobs each needed per unit of output show falling trends. We suggest these trends can be realistically extrapolated into the future using best-fit decay curves. Employing staff is a major cost for all establishments in the services industry, so it is not surprising that there is continuous pressure to reduce these costs by productivity gains to stay in business in a competitive market. However, if unemployment overall is not to rise as jobs-per-unit-output falls, then the services industry will need to compensate for the loss of jobs. The historical data shows that the economy has managed to accomplish growth of the services industry but with a consequent large draw on investment, the thickest FCF line in Figure 4. We stress that the 4see framework reveals the physical requirements of the services industry thought by many to be virtual. The Sankey diagram of the complete UK economy shows graphically how difficult it is for policy to effect radical change in the pursuit of new industries, rebalancing between industries, climate change mitigation, and environmental repair. Alternatives need access to investment, yet it is clear that redirecting sufficient capital from one industry to another has consequences and opportunity costs. A corollary is the possibility that services industry will need continually to expand posing the challenge of when consumers’ demand for services might saturate, thus stimulating large increases in unemployment. Alternatively, the working week will have to be shortened to retain high rates of access to paid work and workplace contribution.

By rationalising a large set of disparate accounting procedures, the framework integrates procedures that collect, curate, inter-relate, and produce time series of national data essential to longer term strategic policy making. The process of taking ratios of key time series data gives functional relationships that could or should be at the centre of political and industry decision making. Our immediate goals for the use of the 4see approach are to derive a base case scenario out to 2030 or 2050, building on the foundation of the rationalised and robust twenty-year history. This will allow us to focus on strategic questions of economic and societal structures in one or two human generation’s time. This also allows the unpicking of complex sets of sometimes hidden assumptions behind long term policies, such as greenhouse mitigation and workforce development. Once a base case scenario is established, the simulation-through-time capability of 4see allows simple one-issue policies (for example, heat pumps for housing or electric vehicles) or more complex sets of interacting issues (for example, accelerated deployment of renewables or reduced household consumption) to be derived.

With the advent of ‘open data’ and ‘big data’ the 4see framework will become richer as it has been designed to make easy the addition of new annual data. The modular structure of data within 4see allows for new datasets to be included. Rolling out this framework and procedures across different countries could foster cross-country comparisons on an exactly comparable basis that should catalyse cooperation on global issues that have started to be tackled individually by governments. The robust data rationalisation and simulation capabilities allow potential transition points or physical un-realities to be highlighted easily. The tension between science and economics in many policy areas cannot be lessened due to ongoing conflicts of methods and rules. Because the 4see approach accepts all datasets and accounting procedures as pragmatically equal, it gives little scope for disagreement between competing views. How policymakers then react to these tensions is the key determining factor for a transition to a lower carbon economy.

Acknowledgements
This research was financially supported by Arup’s internal Design and Technical Fund. We are grateful for the care taken in converting data from the 4see framework into accurate, readable Sankey diagrams to Martin Fernandez de Cordova and Diana Kovacheva, both interns in the Arup Foresight group.

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