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A framework for characterising an economy by its energy and socio-economic activities

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ABSTRACT

Investigating the energy use of an economy in a resource-constrained world requires an understanding of the relationships of its economic, social, and energy-use elements. We introduce a novel whole-economy analytical framework which harmonises multiple national accounting procedures. The economic elements align with the International System of National Accounts. In a modular fashion, our 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. We use novel Sankey diagrams to visualise snapshots of the whole system. The framework is neither an exclusively economic, physical, nor social model. It upholds the integrity of each world-view through retaining their unique time-series datasets. As this framework is agnostic to the way in which a nation organises its economy, it has the potential to reduce tension between competing models and philosophies of economic development, environmental refurbishment, and climate change mitigation.

1. Introduction

Researching the possible economic, social and environmental impacts of choices made by economic and physical policymakers and planners is critical to improving the decision-making process (Ayres, 2008; Baptist & Hepburn, 2013; Leontief, 1993). We introduce an analytical method capable of assessing national investment capacity in technical infrastructure such as for energy generation. The method addresses the systemic economic and bio-physical (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 (Ayres & Warr, 2012; Leontief, Duchin, & Szyld, 1985; Pedersen & de Haan, 2006). 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 & Harchaoui, 1997) and can lead to perverse subsidies (Baptist & 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

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Box 1: Abbreviations and acronyms

BPM6	Balance of Payments and International Investment Position Manual, Sixth Edition
CFC	consumption of fixed capital
CPC	Central Product Classification
CVM	chain volume measure
FC	fixed capital
FCF	fixed capital formation
GDP	gross domestic product
GFCF	gross fixed capital formation
GVA	gross value added
HGV	heavy goods vehicles
ISIC	International Standard Industrial Classification
LGV	light goods vehicles
NPISH	non-profit institutions serving households
P-codes	transaction types of an economy
S-codes	sector types of an economy
SEEA	System of Integrated Environmental and Economic Accounting
SNA	System of National Accounts
SUTs	Supply and Use Tables

modern information technology systems, enabling historic and contemporary data to be made readily available (ONS, 2012a, 2012b). 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 & Blades, 2006). 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.

1.1. The bio-physical approach

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 & Blades, 2006; United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, & World Bank, 2009). 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.

There has been interest in hybrid models to bridge the top-down and bottom-up divide (Hourcade, Jaccard, Bataille, & Ghersi, 2006); the bottom-up part has principally been considering technology-driven models. Our approach accounts for the energy demand (positive or negative) created by the adoption, deployment, and use of energy within an economy with physical and economic constraints. 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. Our aim is to work within economic constraints such as those imposed by limited Gross Fixed Capital Formation (GFCF), the upstream need for fixed capital and those imposed by the availability of energy (exergy) (Box 1). The SEEA (System of Integrated Environmental and Economic Accounting) accounting system contrasts with this by showing how natural resources and ecosystem inputs are drawn into the economy, and products and residuals are generated (European Commission et al., 2012). The framework is consistent with the System of National Accounts (SNA; United Nations et al., 2009), but unlike SEEA not a satellite to it (United Nations, 2011). We are not producing an accounting methodology, but a framework for analysing accounting data that will lead towards the specification of a model.

We want to understand the trade-off between complexity and how much information is 'just enough' to gain insight into how an advanced economy can make a critical transition. This necessitates a deep understanding of the relevant data and its limitations. A robust and flexible model for data analysis is required. The aim of our research is to 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 is 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.

1.2. The structure of this paper

This section spells out the key stages in the method which build up our 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 sections draw together our conclusions and suggest how this framework will be operationalised in a dynamic model.