ARTICLE IN PRESS

Energy Policy xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The social metabolism of Scotland: An environmental perspective

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ARTICLE INFO

Keywords:
Energy
Emergy
Social metabolism
Rural
Economy

ABSTRACT

The paper presents the results of a study that developed and applied social metabolism methods to assess the sustainability of a regional economy, particularly the dynamics related to changes in the production and use of energy. The first objective of the study was to assess the feasibility of using existing secondary data sources as a basis for sub-nation state and regional analysis (with the regions in this case differentiating the area based on rurality). The second was to structure the outputs of the analysis in ways that provided comprehensive yet succinct and interpretable assessments of the balance of flows of material, energy and money that underpin the economy, with the intention that ultimately these assessments would be used to inform policymaking. The paper provides an introduction to the key concepts used within social metabolism analysis particularly the use of emergy (a measure of the cumulative environmental support provided to a social-ecological system). This is a unifying metric into which the myriad flows within an economy can be translated and combined in meaningful ways. It does so by, preserving information on both the quantity and quality of flows and so avoiding the need for arbitrary weightings. The paper presents a range of options for the use of emergy-based metrics that could be used to inform policy making. Comparisons for the years 2001 and 2010 are made at country level for Scotland and for three degrees of rurality. The analysis highlights how decisions on the share of the offshore energy sector attributed to Scotland and on the share of services (particularly those imported from beyond U.K.) have profound effects on the sustainability trajectory of the economy and the conclusions that might be drawn for policy. The paper concludes that the methods have the potential to add value to existing administrative datasets, and provide new perspectives that may be of value to policy making, but acknowledges that challenges remain in translating this potential into tangible use within policymaking.

1. Introduction

When assessing the sustainability of a regional or a national social-ecological system, there are so many different single-dimension trends of environmental, social, and economic aspects of these systems that they cannot be coherently assessed without resorting to some form of synthesis to derive one or a limited set of indicators that coherently and systematically represent sustainability outcomes.

The leading international organizations, such as the International Trade Centre (ITC), quantify traded goods in terms of their mass and the money paid for them. This is because economic assessments of trade most often only focus on the money balance. These analyses do not take into proper account the quality of the traded resources, as well as the related environmental consequences, both from the point of view of the depletion of energy and materials and of the pollution generated by extraction and preliminary processing in the exporting country (Bargigli et al., 2004; Pereira et al., 2013).

Performance indicators for industrial parks, regions and nations have been developed, based on well-known assessment methods: embodied energy, material flow analysis (MFA), life-cycle analysis (LCA), CO_2 emissions, and economic returns (Geng et al., 2012). These indicators individually or in combination do not necessarily provide a fully adequate characterisation since they were not designed from the outset to assess whole-systems, closed-loops, and feedback features that are key characteristics of a circular economy (Geng et al., 2013). Some disregard flow quality and characteristics and the complexity of interactions between the natural environment and socio-economic systems (Huang et al., 2006).

To overcome the above-mentioned limitations of the unidimensional or narrowly focused analysis at the national scale, several scientists examined for UNEP the material and energy bases for national economies (UNEP, 2012). They created an extensive database, the National Environmental Accounting Database (NEAD), compiling global energy, material and money flows, aggregated by national political boundaries, with systemic indicators such as the environmental load and the resource use intensity, among others. For more

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http://dx.doi.org/10.1016/j.enpol.2016.09.058
Received 29 February 2016; Received in revised form 19 September 2016; Accepted 26 September 2016
Available online xxxx

Please cite this article as: Viglia, S., Energy Policy (2016), http://dx.doi.org/10.1016/j.enpol.2016.09.058

than 130 national systems, environmental sources, data for production, extraction, and trade flows were used to implement environmental evaluation with the Emergy Accounting Method (EMA) (Odum, 1988, 1996; Brown and Ulgiati, 2004a, 2004b). EMA incorporates the environment by accounting for the work done by nature to generate resources (natural capital) and provide ecosystem services. It expresses all resources on a common basis, in solar equivalents (abbreviated sej, for solar emjoules), which makes the work of environmental systems and human systems comparable and analytical insights more coherent. It recognizes that the human/economic system is a subsystem of the larger geobiosphere system that provides flows of energy and material resources that directly or indirectly contribute to human quality of life, but which often have no markets and cannot meaningfully be valued using willingness-to-pay (Brown and Ulgiati, 2011).

Scotland is not included in the NEAD system, and no other material, energy and emergy-based assessments of the country as a whole are known to be available. Given the potential diagnostic value of emergy-based characterisations, as seen from the scientific literature (Brown et al., 2009; Gasparatos and Gadda, 2009; Giannetti et al., 2013; Lou and Ulgiati, 2013; Siche et al., 2008; Geng et al., 2013), the objective of this research was to assess the feasibility of implementing such analyses for the Scotland as an example of below-national scale analysis. Therefore, EMA was applied in order to generate country-wide, consistent performance indicators.

The outputs from the research, including this paper, are intended to serve as an initial basis for discussion with analysts and policy officials of the Scottish Government. The work is particularly relevant given the commitment by Scottish Government to reduce emissions of greenhouse gasses by 43% by 2020 and by at least 80% by 2050. This commitment needs to be achieved within the Government's strategic purpose of creating a more successful country, with opportunities for all of Scotland to flourish, through increasing sustainable economic growth. Emissions reduction targets will drive new thinking, new technologies, new solutions and new investment that will ensure Scotland is an early adopter at the forefront of a sustainable, modern, low-carbon economy (Scottish Government, 2011).

In this policy context, the analysis of social metabolism is particularly informative to identify the opportunities and constraints in reaching the Government's goals. In this paper we present an assessment of Scotland in its present business-as-usual dynamic, to serve as a benchmark for improvement scenarios. We also generated assessments for urban and rural Scotland based on three different degrees of rurality (see Section 2.1), since it is likely that the Scottish Government will need to reconcile the needs of these significantly different social-ecological systems and their interdependencies in its future policy making.. The paper also highlights the dramatic effects that assumptions made on how North Sea fossil energy extraction is accounted for have on the indicators and the need to carefully consider how to fairly account for such activities in the assessment of the sustainability of Scotland.

2. Materials and methods

2.1. The investigated system

The total land area of Scotland is about 7.8 million hectares. Located in N.W. Europe, it is exposed to prevailing westerly airflows, with a long coastline, having substantial areas with mountainous terrain and an extensive continental shelf area.

The study evaluates Scotland for two years 2001 and 2010. The main body of the results are for Scotland as a whole using the current administrative boundaries between Scotland and rest of UK. Options for assigning offshore activities and material flows are also included with the offshore (mainly oil and gas) sectors excluded, or included based on Scotland's share of the UK population or included according to the median line principle used for fisheries demarcation purposes, as suggested by Kemp and Stephen (2008). The first highlights the character of the economy without the offshore sectors, the second the *status quo* and the third a hypothetically enlarged share that could be assigned to an independent Scotland. The country was also differentiated using the degree of rurality to highlight the challenges of deriving metrics to support policy making at smaller focal scales.

Of the total area of Scotland, 94% is rural, as designated by the Scottish Governmentsince the settlements, where present, have populations of less than 3,000 persons. The classification of an area as rural is further differentiated by drive times to larger settlements with two sub-classes. Accessible rural areas are those with a less than 30 min drive time to the nearest settlement with a population of 10,000 or more (25% of the total area of Scotland). Remote rural areas are those with a greater than 30 min drive time to the nearest settlement with a population of 10,000 or more (69%).

The Scottish population is heavily concentrated in non-rural areas (83%, referred to in the figures and tables as the “Rest” of Scotland). From 2001 to 2010, there were no substantial changes in the balance between accessible, remote and other areas of Scotland, with an overall small movement of population from urban to accessible rural areas (1% of national population, though this represents a much larger share of the population of rural areas).

To provide a first illustration of the differences, land area, population and GDP values were disaggregated (the latter on the basis of employment and population shares). For the rural-urban comparisons in this study there were insufficient resources available to attempt to disaggregate GDP values on a more sophisticated geographical and socio-economic basis (Table 1).

2.2. Methods

Investigating only the behavior of a single process or seeking maximization of one parameter (efficiency, production cost, jobs, etc.) is unlikely to provide sufficient insight to adequately support policy-making intended to promote sustainability of a complex coupled social-ecological system like Scotland. EMA, however, enables more holistic approaches to be taken as it expresses stocks and flows of resources, goods and services in units of the same quality, the solarenergy that is used up in transformations directly and indirectly to make a product or service(solar emjoules (sej)). EMA can therefore provide a biophysical perspective complementing market-based evaluation techniques. EMA also looks at the environmental performance of a system on the global scale (that is it considers dependencies and effects beyond the boundaries of the systems of interest). It also takes into account all the free environmental inputs such as sunlight, wind, rain, as well as the indirect environmental support embodied in human labour and services, which are not usually included in more traditional embodied energy analyses. Moreover, the accounting is extended back in time to include the environmental work needed for resource formation. According to the emergy calculation procedure, when the recharge of a selected natural stock (i.e. water, organic soil, wood, etc.) exceeds or equals extraction on a national basis it is not accounted for in the analysis. Odum's (1996) book provides a full discussion of emergy as well as many articles (Brown and Ulgiati, 1997, 1999, 2001, 2004a, 2004b, 2007; Ulgiati and Brown, 1998, 1999, 2000).

A systems diagram (Odum, 1996), such as the one in Fig. 1, is used to show the pre-analytical choices of entities, relationships, inputs and

Table 1
Land, population and gross domestic product share among remote and accessible rural and rest of Scotland.

	2001			2010		
	Rest	Accessible	Remote	Rest	Accessible	Remote
Land area	6%	25%	69%	6%	25%	69%
Population	83%	11%	6%	82%	12%	6%
GDP	86%	9%	5%	85%	10%	5%