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Analysis of complementary methodologies to assess the environmental impact of Luxembourg's *net consumption*

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ABSTRACT

The choice of accounting methods and indicators to support national stakeholders and public authorities in environmental decision-making policies is made difficult by the extensive number of available tools and the general divergence of scientific opinions on their effectiveness. In this paper, a set of life cycle-based approaches are compared and a methodological framework is recommended to support policy makers in the evaluation and choice of environmental impact mitigation strategies. The *net consumption* (=*production* + *imports* – *exports*) of Luxembourg, taken as a case study, is inventoried based on different Environmentally Extended Input–Output (EE-IO) scenarios and further assessed using the Ecological Footprint (EF), ReCiPe and Solar Energy Demand (SED). All the compartments of resources extraction and pollutant emissions and the main environmental impacts generated by the Luxembourgish economic trade-offs are evaluated. Results highlight the need for higher consistency in the use of EE-IO tables mainly because of the uncertainty affecting the environmental extensions (EEs). This aspect plays a major role when applying different assessment methods and relevant changes in terms of overall environmental impact are observed according to different sets of resources and emissions inventoried. These changes, however, do not substantially influence the results at the level of single economic sector's contribution. Regardless the consumption scenario and the indicator considered, the financial and banking sectors contribute to more than 40% to the total EF, SED and ReCiPe results. Strengths and weaknesses of each indicator are discussed, and direct and indirect contribution analyses by sector allowed outlining strategies for impact mitigation.

1. Introduction

Nowadays a plethora of assessment methodologies are available to support national stakeholders and public authorities in the process of developing and implementing resource management regulations or environmental impact mitigation strategies (Kissinger et al., 2011; Böhringer and Jochem, 2007; Wiedmann, 2009). These methodologies are often established as policy support instruments, even though they are neither easy to interpret by non-experts, nor they are entirely recognized for the information value they provide (Bauler, 2012; Mayer, 2008; Moldan et al., 2012).

The Ecological Footprint (hereafter EF) methodology introduced by Wackernagel and Rees (1996) has been more and more discussed and used as a resource accounting tool (Kitzes et al., 2009) during the last decade as a result of its global approach and ease of understanding. The concept of EF is based on the evaluation of bioproductive land and water areas used by a nation to produce the resources it consumes and to absorb the generated CO_2 emissions over 1 year. The final result, i.e. the per capita consumption of a specific country, is usually expressed in global hectares referring to the

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world-wide origin of the resources and, thus, stressing the consumers' responsibility. Despite its promising features, EF has been criticised for the rough assumptions backing its calculations and some authors even question the concept itself. For example, Fiala (2008) argued that it is not surprising that cities like Vancouver or countries like the Netherlands with a high population density per hectare have much more important EF than less economically powerful countries such as Benin, Bhutan and Costa Rica.

A novel indicator aiming to quantify the equivalent solar-energy of human commodities production, i.e. the Solar Energy Demand (hereafter SED; Rugani et al., 2011), attempts to expand the system boundaries of EF to include a much larger number of resources. The SED is based on the rationale behind the emergy concept (Odum, 1988, 1996), despite emergy does not apply allocation criteria in the case of co-products from multi-output process. Moreover, SED does not account for a number of inputs usually included in emergy analysis, e.g. human labour, information and several ecosystem services (Rugani et al., 2011). Both SED and emergy can be regarded as an approximation of the appropriation of environmental work (evaluated in terms of solar energy) by a human economic system through the natural resources consumed. A lower appropriation of environmental work per unit of product is conventionally seen as a measure of sustainability (e.g. Raugei, 2011), despite that claim has not been fully proven in literature. By expanding further the boundaries, in order to include the pollutant emissions and the related environmental impacts generated by the human economy, Life Cycle Assessment (LCA; ISO 14040, 2006) is a widely recognized and used methodology among stakeholders. LCA is based on a comprehensive inventory of pollutant emissions and resources consumptions involved in the life cycle of a product or in human economies, which are further translated into potential environmental impacts referring to reference environmental conditions. Among the available Life Cycle Impact Assessment (LCIA) methods, ReCiPe 2008 (Goedkoop et al., 2009) has a wide coverage of environmental problems and uses up-to-date impact characterization models.[1] Both the SED and ReCiPe, which share a common life cycle inventory (LCI) methodology, suffer from not having been sufficiently applied at macro-scale to assess the environmental impacts of a country's consumption. Historically, they were developed to assess environmental burdens at the micro- and meso-scale of technological processes. In this regard, the use of input–output models (see for example Joshi, 1999; Suh et al., 2004) for the LCI may allow extending the process oriented LCA approach to the larger scale of a country, including economic activities (sectors) at macro level (e.g. Suh and Huppes, 2002; Crawford, 2008). Input–Output Tables (hereafter IOTs) describe the intra- and inter-connections between economic sectors and economic markets, quantified in currency (e.g. euros) (European Commission, 2008; Leontief, 1986). Further to the economic exchanges, specific environmental extensions (hereafter EEs) have been inventoried and linked to IOTs, characterizing both the inputs (natural resource consumptions and land use) and the outputs (pollutant emissions) related to each economic sector's inventory (Tukker et al., 2006).

These methods and approaches has raised a debate on the suitability and reliability of the environmental accounting methods, which hamper their use to support decision making processes and confuse stakeholders and policy makers (e.g. Böhringer and Jochem, 2007; Mayer, 2008; Bauler, 2012; Galli et al., 2012; Moldan et al., 2012). In this paper, a step forward is taken by discussing the different criteria behind the above-mentioned assessment approaches in order to propose a general methodological framework to support the definition of consumption reduction strategies and policies at the level of a country. More specifically, the aim is to assess the environmental impact due to the *net consumption* of Luxembourg, taken here as a case study, through the application of EF, SED and ReCiPe to different economic inventory scenarios developed by combining several Environmentally Extended Input–Output (EE-IO) models. The strengths and weaknesses of the approaches and scenarios are analysed with special emphasis on the benefits for potential applications in policy support.

Assessing the country's consumption patterns is a relatively new paradigm of looking at the impact of using goods and services within a regional economic context, which contrasts to the more traditional production-oriented one used, e.g. for the GDP calculation. In principle, the main difference is that a consumption perspective allows accounting not only for the impact of producing commodities inside the country (e.g. direct GHG emissions) but also outside (e.g. indirect GHG emissions) (e.g. Peters, 2008). The interregional EF strand, for example, reveals that consumption driven demand for imported goods and materials imposes significant and often unrecognized (by importers) burdens on productive ecosystems in exporting regions (Kissinger et al., 2011). Therefore, the identification of consumption patterns of the countries is a key challenge to address environmental sustainability policies and to reduce global energy and natural resources consumption (Barber, 2003). This is particularly true for the developed economies, where increasing demand for imported goods and services leads to a rise in pollution and greenhouse gas emissions from the production in other countries (Davis and Caldeira, 2010; Larsen and Hertwich, 2009; Wiedmann et al., 2006, 2007).

The paper is structured as follows: first a synthesis of Luxembourg's consumption patterns is presented in Section 2; a general overview about the methodologies and the assessment framework is given in Section 3; results from the methods application to the Luxembourg's case study are presented in Section 4 and discussed in Section 5; final conclusions and outlook on future applications are drawn and illustrated in Section 6.

2. The Luxembourg case study

The Grand Duchy of Luxembourg is a landlocked country located in Western Europe (Fig. 1). Based on data from Statec (2012), it has a resident population of around 469,100 people (data for the year 2005, 31st December 2005) over an area of

[1] A *characterization model* in LCIA is an assessment model allowing the calculation of specific impact category results, e.g. acidification, eutrophication, climate change, etc. from the LCI data of resource consumptions and/or pollutant emissions. A *characterization factor* is derived from a characterization model to convert an assigned LCI result to the impact category indicator result (ISO 14040, 2006).