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# A societal metabolism approach to job creation and renewable energy transitions in Catalonia

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ABSTRACT

This paper examines the feasibility of renewable energy transition scenarios and employment requirements on a backdrop of the objectives as described by the energy and climate change plan in Catalonia (PECAC 2012–2020). The analysis uses the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach as a framework for bringing together information regarding the demographic change, allocation of working hours, as well as mapping energy flows metabolized through the different compartments of the socio-economic system. Results indicate that the implementation of the energy plan in Catalonia would result in an increase in the overall energy metabolic rate by 2020, meaning 10% more energy is to be consumed per hour available in society. We conclude that this increase is linked to the need for greater primary energy sources for a transition to renewable energy sources, as well as the need for increasing skilled jobs to perform these tasks in the energy sector. For the case of Catalonia, we conclude that this would correlate to a requirement between 8000 and 23,000 new jobs that will imply a shifting in current metabolic patterns should such a transition take place.

## 1. Introduction

### 1.1. The complexity of a renewable energy transition

Energy has played a fundamental role in economic and social development. Energy availability is linked to major trends of growth, development, evolution, and in some cases, to the decline experienced by many forms of social organization (Tainter, 1990). Traditionally, economic growth has been measured by changes in the production of goods and services. These goods and services are physical manifestations of net energy once delivered to society (King and Hall, 2011). Based on this relationship, over the years, several studies have scrutinized the strong correlation between gross domestic product (GDP) and energy consumption of societies (Alcántara and Duarte, 2004; Chontanawat et al., 2006; Granger, 1969; Sims, 1972; Yu and Hwang, 1984).

On the other hand, institutions and analysts in the energy sector point at the depletion of the rate of return of fossil fuel extraction (Aleklett and Campbell, 2003; Heinberg, 2007), as a cause of decreasing energy return on investment rates (EROI) (Hall et al., 2009; Inman, 2013; Lambert et al., 2012). This means that a higher proportion of energy production is forwarded to obtaining energy itself because the easy-and-cheap sources have already been exploited, so there is less funding for societal activities other than generating energy itself (Hall et al., 2014).

The above points describe a model with a positive loop that feeds the need to use a greater amount of energy (Fig. 1). In other words, a more economized society will consume more energy and in turn, this energy will be more difficult to obtain considering that, investment rates are becoming lower for almost all sources of primary energy production. This can then be translated to an external pressure on energy consumption patterns taking into consideration reducing overall EROI. Thereafter, one can question the overall development and growth patterns we wish to or are able to, based on these biophysical constraints, replicate for the future.

Moreover, regarding climatic change, two-thirds of the emissions of generated greenhouse gasses (GHGs) are attributable to the energy sector (Mackay, 2009), a fact that suggests the importance of taking proper actions in order to stabilize the rate of current GHG emissions in this domain (Jiang et al., 2016; Zeng et al., 2016b). The environ-

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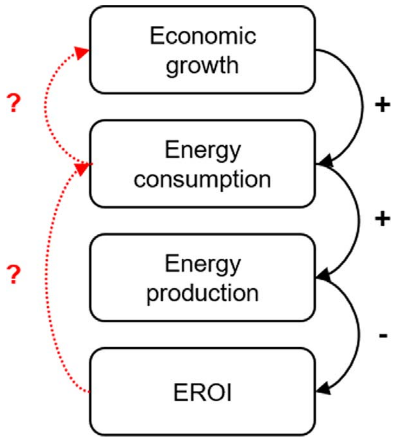


**Fig. 1.** Causal loop diagram of energy consumption.

mental impacts caused by energy production increase the urgency of shifting the current energy model. Planning and establishing energy policies which guide us in transitioning to a more sustainable energy model (Folch et al., 2005; Maure and Baras, 2010). In general, energy plans have three strategic lines of action: (1) reduction of energy consumption (primary and final); (2) efficient distribution networks, which aims at reducing losses in energy transportation and delivery; and (3) implementation of renewable energy products and services. This paper focuses mainly along this last line of action: it aims at being an auxiliary tool in the decision-making process during the transition to renewable energies, considering the metabolism that societies portray and how these metabolic profiles will be modified based on this renewable energy transition.

In order to follow any of these lines of action, it is necessary to make a transition to renewable energies to stop relying on non-renewable fuels. However, the structural change of the primary energy sources (PES) of this transition will entail changes in the social structure that have not yet been analyzed holistically (Diaz-Maurin and Giampietro, 2013).

A transition based on renewable energy not only must reduce emissions, or reach a percentage share of the total energy consumed by society, but it also must ensure that desired societal functions can be executed through renewable modes of energy production. This transitional process must remain flexible to adapt to changing conditions under uncertain futures and functions of complex societal system (Smil, 2003). Therefore, energy transitions need to entail a long-term structural change in energy production systems, modes of consumption and accompanying a significant change in energy policies as well (Iychettira et al., 2017). The growth paradigm should be replaced with a new set of political and ethical pillars, which must eventually reach a "prosperous way down" (Odum and Odum, 2006).

Although it seems that a change in the energy sector structure is inevitable, we must ask ourselves whether societal conditions exist to achieve the objectives of energy plans. Among other variables, fundamental ones to take into consideration are:

- **Population structure**: The low fertility levels projected for Europe and the increase in life expectancy imply a process of population aging for this region. It is expected that demographic changes have a direct effect on economic growth, as a result of changes in the factors of production (Crespo Cuaresma et al., 2015). Changes in the workforce demographic structure will lead to changes in aggregate human capital in the form of experience and productivity (Kögel, 2005).
- **The standard of quality of life**: The quality of life depends on the possibilities that people have to adequately meet their basic human needs (Max-Neef, 1993). Although human needs are constant, the way they have been satisfied through time or among societies varies, depending on the energy availability (Smil, 2008). The basic goods and services that we require in modern civilization are highly dependent upon the delivery of net energy (Hall et al., 2009; Lambert et al., 2014).
- **The metabolisms of societies:** Diversity of activities carried out within the different compartments of society (Sorman and Giampietro, 2013). This refers to the structure of the productive sectors and the role they play in society, according to their hierarchy in the appropriation of flows, and occupation of funds.

The aim of this paper is to determine the feasibility of implementing renewable energy plans in the autonomous region of Catalonia (Spain) for 2020, with respect to the conditions and limitations established by the theory of urban metabolism (Georgescu-Roegen, 1971; Giampietro and Mayumi, 2000a, 2000b) and from comparative metabolic patterns (how and why we use resources), based on the forecast for supply - demand that is set in our case study.

Our analysis takes on from studying the objectives set out by the *Pla de l'Energia i Canvi Climàtic de Catalunya* (PECAC) 2012–2020 (en., Climate Change end Energy Plan for Catalonia, 2012–2020) and its scenario *Intensiu en Eficiència Energètica i Energies Renovables* (en., Intensive in Energy Efficiency and Renewable Energies (IER)) (Institut Català d'Energia, 2012). This is done through the study of energy flows in Catalonia and considering its hypercycle and dissipative processes (Ulanowicz, 1986). The hypercycle processes produce all material goods used by a society (including energy). The hypercycle refers to the fact that this sector produces a surplus of material goods (Fix, 2015). In contrast, dissipative processes are only consuming ones, and they do not produce any material goods. The paper focuses on the relationship between human activity and energy consumed (within the hypercycle and dissipative processes), and aims at validating that objectives set out in PECAC 2012–2020 are the current patterns of energy consumption. For doing so, energy flows for the Catalan region are analyzed, starting with primary energy sources, with an emphasis on renewable energy. Consumption and losses related to generation and distribution of electrical energy and fuel are also included, as a previous step to reach final consumption in every productive sector. Complementarily, distribution profiles of human activity (hours available to perform each activity) within each productive sector are also included, as a means to describe social and cultural characteristics of the society under study.

## 2. Methodology

### 2.1. The methodological framework: Transitioning from social metabolism to societal metabolism

The concept of social metabolism is used to describe the mode in which human societies organize their growing exchanges of energy and materials with the environment (Ayres, 1997; Fischer-Kowalski, 1998; Giampietro and Mayumi, 2000a; Haberl et al., 2011; Martinez-Alier, 1987). Social metabolism begins when societies appropriate the materials and energies of nature (input), and it ends when these are deposited as waste, fumes or residues in natural areas (output). Between these two steps, there occur other processes, where energy and materials are circulated, transformed and consumed (Toledo, 2013). Therefore, the process of social metabolism involves appropriation, transformation, and distribution of energy and materials into goods and services that are used by society in order to maintain different dissipative sectors (Fig. 2). In this sense, energy metabolism describes how society uses energy inside the productive sectors for its continued operation.

According to Fischer-Kowalski (1998), the study of the socio-economic metabolism along with the flow of materials can be a very useful tool in the interdisciplinary analysis of environmental performance indicators. This contributes to our understanding of the