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Modelling sustainability performance to achieve absolute reductions in socio-ecological systems

Breno Nunes [a, *], Roberto C. Alamino [b], Duncan Shaw [c], David Bennett [d, e]

[a] Aston Business School, Aston University, UK
[b] School of Engineering and Applied Sciences, Aston University, UK
[c] Manchester Business School, Manchester University, UK
[d] Department of Technology Management and Economics, Chalmers University of Technology, Sweden
[e] Business School, University of South Australia, Adelaide, Australia

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ABSTRACT

As the world's natural resources dwindle and critical levels of environmental pollution are approached, sustainability becomes a key issue for governments, organisations and individuals. With the consequences of such an issue in mind, this paper introduces a unifying approach to measure the sustainability performance of socio-economic systems based on the interplay between two key variables: essentiality of consumption and environmental impact. This measure attributes to every system a 'fitness' value i.e. a quantity that reflects its ability to remain resilient/healthy by avoiding ecological, social and economic collapse as it consumes the available resources. This new measure is tested on a system where there is a limited supply of resources and four basic consumption types. The analysis has theoretical implications as well as practical importance as it can help countries, organisations or even individuals, in finding better ways to measure sustainability performance.

1. Introduction

The globalisation of markets has encouraged millions of people to adopt consumption patterns of Western countries (Prahalad and Hart, 2002). However, increasing rates of consumption puts pressure on those same markets, for example, due to the loss of biodiversity, insufficient energy supply and the pollution of natural resources (WRI, 2002). These pressures will be accentuated if consumerist life-styles spread through emerging large-population countries such as China, India, Indonesia and Brazil. The rapid growth of energy consumption in China and India alone is evidence of this trend, making global sustainability a concern for policy makers, business leaders and scientists (IEA, 2010).

Despite advancements in environmental policies, business practices and public awareness, doubt exists over whether the magnitude and velocity of improvements are sufficient. To reduce environmental damage, the Stockholm Resilience Centre (Rockström et al., 2009a, 2009b) recommends the adoption of planetary boundaries i.e. limits to consumption that respect the planet's ability to renew itself. The concept of planetary boundaries has been criticised over its use of controversial thresholds and fundamental principles of irreversible damage (Biello, 2009). Among critics, the Breakthrough Institute (Nordhaus et al., 2012) argues that there is no evidence that the boundaries will lower the impact from human activities. Also, they claim that the setting of boundaries was arbitrary and that a lax boundary may accentuate degradation. Regardless, the planetary boundaries concept has occupied institutions, including the United Nations High-level Panel on Global Sustainability, and could translate to corporate sustainability (Whiteman et al., 2013). Despite controversy, thresholds may become necessary at global and local levels (Biello, 2012), encouraging debate on the planet's carrying capacity, the use of thresholds (Martinet, 2011), cap-and-trade systems (MacKenzie and Ohndorf, 2012) and individual quotas for firms (Holland and Schnier, 2006; Péreau et al., 2012).

The debate between these views is based on models of sustainability performance, which consider scenarios with homogenous 'baskets of consumption' where all items are essential. This simplification may sometimes be useful but needs refinement to increase its applicability, for example, to classify goods/services using two dimensions of sustainability: (i) their essentiality and (ii) environmental impact. Each basket of consumption can represent a

* Corresponding author.
E-mail addresses: b.nunes@aston.ac.uk, brenotsnunes@yahoo.com.br (B. Nunes).

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group of goods/services having similar levels of essentiality and environmental impact. Their consumption is influenced by national policies, resource availability, price, market dynamics and other systemic forces.

We embed essentiality in a model of the 'general health' of a system which we call the *system fitness*. In ecology and other scientific areas (Richter and Engelbrecht, 2014), fitness is defined as the ability of the system to thrive in its environment. We define system fitness as a measure of how far a system is from collapse by requiring a balance between the satisfaction of essential needs and the environmental impact created by meeting these needs. In this paper we build a simplified model to explore how essentiality and environmental impact affect sustainability performance measurements and sustainability strategies.

The paper starts by reviewing concepts of sustainable development and models of sustainability performance measurement. It then introduces concepts relevant to our model, describes its methodology and explains how sustainability performance is measured. The illustration of the model follows, and conclusions complete the paper.

2. Sustainability and its management

Despite debates about our planet's sustainability, several issues remain unexplored. The concept of sustainable development is difficult to translate into practice for countries, cities, companies and even personal life-styles (Barber, 2007). This difficulty relates to the complexity and uncertainty in the design, implementation and assessment of environmental strategies and sustainability performance indices (Bossel, 1999; Boyko et al., 2012; Gasparatos et al., 2009).

Consider the often-quoted concept of sustainable development by the World Commission on Environment and Development:

> "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987 p8).

Usually overlooked are the paragraphs that follow this quote adding the aspirational needs of humans:

> "The satisfaction of human needs and aspirations is the major objective of development. The essential needs of vast numbers of people in developing countries for food, clothing, shelter, jobs - are not being met, and beyond their basic needs these people have legitimate aspirations for an improved quality of life. A world in which poverty and inequity are endemic will always be prone to ecological and other crises. Sustainable development requires meeting the basic needs of all and extending to all the opportunity to satisfy their aspirations for a better life." (WCED, 1987 p43–44)

Philosophically, sustainable development implies limits although "not absolute limits, but those imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities" (WCED, 1987 p8). While the concept of need is discussed, how to measure sustainability in different contexts, considering their unequal stages of development, is unclear. Despite the breadth of the concept, two variables can be extracted: essentiality (representing the needs of human beings) and environmental impact (representing consumption of resources). The latter should be minimised to ensure that future generations have access to natural resources (i.e. avoiding an ecological crisis), without neglecting the former, a complex task discussed later.

The difficulty lies in defining an encompassing measure of sustainability performance, which is suggested by the so-called triple bottom line indicators: economic, social, and environmental (Elkington, 1998). These dimensions have been represented graphically as pillars, overlapping ellipses, and circular flows (Cato, 2009), see Fig. 1. However, these do not represent reality and conflict with the concept of environment stated in the ISO 14004 Environmental Management Systems Guidelines (ISO 14004, 2002):

> "Environment is the surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation" (ISO 14004, 2004)

A better representation is depicts the dimensions as connected inner, outer, and far outer spheres showing the economy as integral to society, and both are within the environment (Hutchinson et al., 2002; Cato, 2009; Nunes and Bennett, 2010). This schema reinforces the need to define appropriate boundaries of an ecological system when measuring its sustainability performance (Ostrom, 2009).

The concept of 'ecological boundaries' is not new. Concerns of being unable to balance demand and supply lie in the philosophical underpinnings established by Malthus (1798). The use of environmental limitations for socio-economic activities is considered in a more complex assessment done by Meadows et al. (1972). King (1995) suggested that environmental conditions should be constantly monitored to avoid ecological surprises (i.e. sudden changes that encourage the environmental collapse). 'Planetary boundaries' extends in this direction.

The literature on sustainable development and sustainability management indicates the need to manage and measure sustainability performance by identifying system characteristics e.g. its boundary and resource availability (Enfors, 2013) followed by the assessment of interventions to promote higher levels of resilience. Next we discuss the measurement of sustainability performance.

3. Measuring sustainability performance

The importance of identifying thresholds within socio-ecological systems is vital to reduce their vulnerability to socio-economic and ecological crises (Young, 2010). Prior to the planetary boundaries approach, Meadows et al. (1972), Wackernagel and Rees (1998), and Meadows et al. (2004) used similar methods to assess the carrying capacity of our planet and tipping points. Such studies sought to understand the complexity of societal, economic and ecological systems through Forrester's concept of system dynamics at industrial, urban, and world scales (Forrester, 1961, 1969, 1971).

At the country level, despite the use of gross domestic product (GDP) and the Human Development Index (HDI) in national policies, these "are failing to capture the full wealth of a country" (UNU-IHDP and UNEP, 2012 p.xi). The Inclusive Wealth Report (UNU-IHDP and UNEP, 2012) includes more realistic measures of wealth using three macro-indicators: natural capital (e.g. forests), human capital (e.g. level of education) and produced capital (e.g. roads).

At the corporate level, there is difficulty in measuring sustainability performance that is aligned to the natural environment's sustainable development (Hart, 1995, 1997). For example, most studies focus on absolute and relative amounts of emissions, waste and consumption (Hahn et al., 2008). However, socio-economic indicators often neglect the value of products and processes to

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