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The system boundaries of sustainability

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ABSTRACT

The energy systems of the Western industrialized nations have passed through different stages of development and fundamental energy crises over the course of their history (14th, 18th, and the end of the 20th century). These crises have contributed decisively to the transformation of the energy system and of European societies.

The various historical energy systems, their system boundaries and the restrictions resulting from them have decisively influenced the opportunities for development in European societies. Based upon this knowledge, the question arises as to what energy system boundaries a future sustainability strategy will have to deal with. The different sustainability concepts (strong and weak sustainability) imply different system boundaries for an energy system aiming at sustainable development.

Climate change, the design of the future energy system, and the finiteness of the fossil energy system are the restrictions for the future energy system. Hence, the boundaries of the sustainability system are determined by four dimensions based on the finiteness of the fossil energy system, the development of a post-fossil energy system, the problem of climate change, and the chosen sustainability paradigm. This sustainability approach could enable sustainable development opportunities for the present generation without affecting the welfare of future generations.

1. Introduction

Since the nineteen seventies, science and society have been discussing the worldwide ecological, economic, and social problems (United Nations, 1972) caused by industrialization, globalization and the energy system (Meadows and Meadows, 1975). Sustainable development is perceived as a strategy for coping with these problems (World Commission on Environment and Development (WCED), 1987). The energy sector is at the center of this discussion (United Nations, 1992b).

2. The energy system and its limits

As long as people have lived on Earth, they have striven to improve their living conditions, and the measure of this improvement is energy. Vaclav Smil called it the "universal currency" (Smil, 1994). Energy is the foundation of all historical social organizations (Schlör et al., 2012), from the hunter-gatherer societies and agrarian civilizations up to modern industrialized civilization (Sieferle, 2001). The history of mankind can hence be divided into three major energy epochs (Fischer-Kowalski et al., 1997): the passive solar age, the active solar age, and the fossil fuel system (Sieferle, 2001), and the future will show whether we will have a fourth energy age, the post-fossil fuel energy system (Burke, 2009).

The energy system of hunter-gatherer societies (Simmons, 1996) was based on a passive unmodified use of solar energy (Smil, 1994) and they intervened passively in a given resource flow and their energy use did not modify natural energy flows substantially (Sieferle, 2006). This changed with the invention of agriculture about 10,000 years ago (Diamond, 1997) with its agrarian solar energy system (Sieferle, 2001) based on agrarian products and wind and water power (Smil, 1994).

The use of fossil fuels (stored solar energy concentrated in "subterranean forests (Sieferle, 2001)") enabled Western European societies to overcome the limitations of the agrarian solar energy system and its energy crises and made the industrial revolution possible (Burke and Pomeranz, 2009). The energy shortage of the passive and active solar energy systems was replaced by a dynamic technology-based system with a large energy surplus, which accelerated economic and social development (Sieferle, 2003a, b). Or as Deffeyes expressed it: "Fossil fuels are a one-time gift that lifted us up from subsistence agriculture (Deffeyes, 2001)."

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The energy systems of the Western industrialized nations have passed through different stages of development and fundamental energy crises (Schlör et al., 2012) over the course of their history (14th, 18th, and the end of the 20th century) (Marquardt, 2005). People consistently came into conflict with the boundaries of the energy systems in the pre-industrialized era (agrarian solar energy system) trying to expand their opportunities for individual and social development (Marquardt, 2005). The fossil fuel energy system in the industrialized era enabled societies to overcome the boundaries of the agrarian solar energy system and to develop an apparently boundless energy system with initially limitless promises of improved welfare (Schlör et al., 2012).

The various historical energy systems, their system boundaries and the restrictions resulting from them have decisively influenced the opportunities for development in European societies (Marquardt, 2005). Based upon this knowledge, the question arises as to what energy system boundaries future social systems will have to deal with (Schlör et al., 2012). The boundaries will depend not only on scientific restrictions on the supply of energy but also on social restrictions derived from the chosen sustainability strategy for future social development. We will show that the sustainability strategies grant different degrees of freedom of choice for the people involved.[1]

3. Sustainability paradigms

Since the Brundtland Report in 1987 (World Commission on Environment and Development (WCED), 1987), the UN Earth Summit in Rio de Janeiro in 1992 (United Nations, 1992a) and the Johannesburg conference in 2002 (United Nations, 2002), 'sustainable development' has been set up as a model for social and political processes, and the concept and its implementation have been discussed by the scientific community and society at large (UNEP, 2011). Now, sustainability is regarded as a solution to present and future societal problems and was enlarged at the Rio +20 conference in 2012 (United Nations, 2012) to include the concept of the green economy (UNDESA, 2012). The green economy is now seen as a process for achieving sustainable socio-economic development (Lorek and Spangenberg). The German Institute for International and Security Affairs (SWP) interprets the green economy as a global concept that "has the potential to function as a central implementation strategy of the guiding principle of sustainable development (Simon and Dröge, 2011)." Based on this discourse, two sustainability concepts (Neumayer, 1999) have been developed to concretize the goal of the green economy, namely, sustainable development (Hamilton and Atkinson, 2006): Solow–Hartwick (Hartwick, 1977) sustainability or the weak sustainability concept (Solow, 1993), and Holling sustainability (Holling, 1973) or the strong sustainability concept (Holling, 1986).

4. Solow–Hartwick sustainability

The authors of the study "Limits of Growth" expressed in their report the opinion (Meadows et al., 1972): "If the present growth trends in world population, industrialization, population, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years (Pestel et al., 1972)."

In their criticism of growth, Meadows and his co-authors come to the conclusion that persistent exponential economic growth would lead to a violation of the ecological boundaries of the Earth (Meadows et al., 1972). Based on these findings, Robert Solow started a discussion about the extent to which optimal growth and a non-decreasing level of welfare will also be possible in the future. With his question he thus laid the foundation for the Solow–Hartwick sustainability concept (Solow, 1974a, b).

In his reasoning, Solow came to the conclusion that it is impossible to reach a non-decreasing consumption path by using non-renewable resources (Solow, 1974b): "If the average product of resources is bounded, then only a finite amount of output can ever be produced from the finite pool of resources, and the only level of aggregate consumption maintainable for infinite times is zero (Solow, 1974b)." Therefore Solow confirms Meadows' analysis of the boundaries of growth. He sought a rule which determines how much can be consumed today and how much has to be invested in man-made capital to also ensure a non-declining consumption level in the future (Dietz and Neumayer, 2007).

In 1977, Hartwick published a solution to the problem outlined by Solow in which he falls back on Hotelling's rule (Hotelling, 1991 (1931)). He assumes that all rents from the extraction of non-renewable resources must be invested in man-made capital (Hartwick, 1977). These rents arise from Hotelling's rule which says that non-renewable resources are used efficiently when their price contains a scarcity component in addition to the extraction expenses. This component contains the return rate of the remaining resource in the resource inventory at market capital conditions (Hotelling, 1991 (1931)).

Hartwick extended Hotelling's rule to include the case of building man-made capital stock by decreasing resource stocks. "Invest all profits or rents from exhaustible resources in reproducible capital such as machines. This injunction seems to solve the ethical problem of the current generation shortchanging future generations by overconsuming the current product, partly ascribable to current use of exhaustible resources (Hartwick, 1977)." Hartwick develops the following rule: "The investment of current exhaustible resource returns in reproducible capital implies per capita consumption constant (Hartwick, 1977)." That is to say, net capital investments are not allowed to become negative (Dietz and Neumayer, 2007), thus guaranteeing that the interests of future generations are considered. Neumayer has shown that Hartwick's rule guarantees a weak sustainable development (Neumayer, 1999).

Therefore one can conclude that the concept of weak sustainability is a direct application of the Hartwick-Solow rule in the case of non-renewable resources (Gutes, 1996). A non-declining consumption path can be achieved, as Solow demands (Solow, 1974b), if the capital stock does not decrease, i.e. the total capital stock (TCS), consisting of natural capital[2] (NC), human capital (HC) and man-made capital (MC), which can be handed over to the next generation but must remain at least constant if the aim is sustainable development (Neumayer, 2003).

The composition of the capital stock which will be handed over to the next generation is not relevant as long as the total capital stock remains steady or increases. The natural capital stock can be diminished if the stock of the other capital goods increases. Therefore for all functions of the natural capital a substitution of other capital goods is possible (Neumayer, 1999).

Weak sustainability can be defined in the tradition of Solow as a development path for the economy, whereby the saving rate of the households is higher than the depreciation rate of the three main capital goods. Hence, the weak sustainability concept is an efficiency strategy.

[1] A traditional social restriction system was the "Allmende" (commons, public ownership) economy in the European Middle Ages (Schlör et al., 2012).

[2] "Natural capital comprises all areas of nature and its ecosystems which produce a continuous flow of goods and services, (Pearce et al., 1992)" See also (Daly and Cobb, 1994).