Chapter 6
Sustainability Assessment of Technologies

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Abstract Sustainability has multiple dimensions. This chapter wants to stress that there is an inherent element of subjectivity in sustainable development that needs to be acknowledged even when sustainable development is at heart about improved states of the environment. Understanding of objectivity, subjectivity, and development can serve a more fruitful discussion about choices in sustainability. The aim of the chapter is to assess available methods for appraising the sustainability of innovation with regard to three key aspects for sustainability assessment: the ability to objectify impacts, the extent to which normative aspects are considered, and the coproduction of impacts between technology and environment.

Keywords Sustainability assessment • Assessment methods • Innovation • Perspectives • Coproduction

1 Introduction

Innovation and technical change are hailed by many proponents as solutions to the sustainability problems of modern society. Examples are electric battery and hydrogen cars, renewable energy technologies, smart grids, and smart housing, to name just a few. The enthusiasm for technological innovations as means toward sustainability is understandable, as they score positively in regard to certain environmental aspects. In this chapter, we want to examine the issue of the sustainability of green technologies and innovation. We will examine methods for environmental assessment and methods for dealing with the normative aspects of sustainable development. The aim of the chapter is to assess available methods for appraising the sustainability of innovation with regard to three key aspects for

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sustainability assessment: the ability to objectify impacts, the extent to which normative aspects are considered, and the coproduction[1] of impacts between technology and environment.

We will argue that sustainability should not be used as a label for technologies, as each and every technology has aspects that are problematic from an environmental point of view. It is better used as a yardstick to measure bigger or smaller contributions of technologies to sustainability criteria.

A second reason for not using the term sustainability as a label is that sustainable development involves normative choices about *what* we value (clean air, quietness), *how much* we value it, and issues of equity and justness having to do with normative views about whether it is right to eat meat, exploit nature in the way we do, and burn fossil fuels in the almost certain knowledge that this gives rise to potentially destructive climate change. A fundamental problem in sustainability assessments is how to *frame* sustainability (Bond and Morrison-Sounders 2013), as something environmental or normative and subjective. Our answer is that one should try to consider each of these aspects.

A starting point of this chapter is that science cannot determine what is sustainable; what it can do is offer evidence about the problems discussed in the name of sustainable development. It can also reveal the different perspectives on sustainability issues and make people mindful of the normative aspects in their own thinking and valuation and the implicit assumptions about progress. The radical implication of this is that sustainability goals cannot be determined in a fixed set of criteria, valid irrespective of time, place, and topic. They have to be agreed upon over time (Bond and Morrison-Sounders 2013; Gibson 2005). This does not mean that anything can go for sustainable development, but simply that sustainable development is neither something objective nor subjective. The chapter does not go into the philosophical aspects of this but examines methods for dealing with subjective and objective aspects and gives attention to the coproduction of impacts. It also draws attention to the political use of labels of sustainability by advocates of certain technologies, hiding problematic aspects of these technologies from public scrutiny (in terms of resource use, emissions, and waste), which enforces our conclusion that sustainability is to be used as a yardstick, not a label.

2 Methods for Assessing Technologies

There are different methods for assessing the sustainability contributions of technologies. To familiarize the reader with some of them, this chapter will first present a spectrum of methods that can be used to assess those contributions

[1] Depending on the scientific community, coproduction is also known as interaction effects.

Table 6.1 Methods for assessing sustainability contributions

Assessment method	Further reading
Cost–benefit analysis	Johansson (1993)
Dialogue methods	Cuppen (2010)
Ecological footprint (proxy methods)	Wackernagel and Rees (1996)
Life-cycle assessment	Baumann and Tillman (2004)
Material flow analysis	Brunner and Reichberger (2004)
Multi-criteria analysis	Figueira et al. (2005)
Scenario methods (incl. backcasting)	Swart et al. (2004), Holmberg (1998)
Procedural framework	
Environmental impact assessment	Glasson et al. (2012)
Integrated sustainability assessment	Weaver and Rotmans (2006)
Strategic environmental assessment	Therivel (2010)

Table 6.2 Classification of sustainability assessment methods

Styles		
Reductionist (indicator)	Holistic	
Monetary	Biophysical	Social
Product (micro)	Area/environment (macro)	

(Table 6.1). The readings included are intended to present an entry point for readers who seek more information.

Recently, efforts have been made to integrate various assessment methods into sustainability assessment. This has led to the publication of several overviews of sustainability assessment methods (Gasparatos and Scolobig 2012; Ness et al. 2007; Singh et al. 2012). Typically, they can be categorized on a number of levels. Such classifications provide insight into the research styles used in an assessment. It shows how the production of *objective information* is attempted (Table 6.2).

Generally, sustainability assessments benefit from recognizing the importance of context (Bond and Morrison-Sounders 2013; Gibson 2005). The overall context consists of the immediate physical context and the social context. The physical aspects are straightforward: a concentrated solar power plant in a sunny desert produces different results from one in a cloudy city. The social context refers to the social actors having views and value frames about the technology or practice which may lead them to reject certain options as inappropriate or fundamentally wrong. The sinking of the Brent spar oil platform serves as a useful example. According to Shell, it was an environmentally sound thing to do. But the general public educated in recycling saw this as an environmentally harmful activity. The sinking was seen as dumping and as setting a dangerous precedent. Shell was wrong to consider the sinking only on environmental and economic grounds. A *perspective-based* method would have revealed that other values were at stake (Cuppen 2010). Dialogue methods are a way to consider the different perspectives on problems and possible solutions and also to make people accept the outcomes of the assessment.

Acknowledging different perspectives and understanding the limits of methods for objectifying knowledge is a prerequisite for undertaking a useful sustainability assessment. They help the analyst to pick the right method and the user to grasp the qualities of an assessment.

A third complication is that the impacts of technologies are *coproduced* and dynamic. Dynamic elements in assessments are normally restrained to cause–effect chains of impacts on the environment. For example, the impact of increased CO_2 levels in the atmosphere on global temperatures, local precipitation levels, and biodiversity changes. These cause–effect chains are very complex and also include feedback effects. Yet, they only focus on the environment and disregard the impact of feedback effects on the technology.

Key technology-specific feedbacks derive from reflexivity, user practices, and rebound effects. The impact of risky technologies depends on the precautionary measures being undertaken to avoid risks and emergency strategies. For every product, the impacts depend on aspects of use and what is being done at the end of its lifetime. Better waste management systems help to reduce environmental impacts. Refrigerators have become more energy efficient, but they have also become bigger, encouraging people to store more food, and in so doing, they contribute to the practice of throwing away food. Impacts are thus tied up with practices, culture, economic frame conditions (prices), and systems of production and consumption. Most sustainability assessments do not include technology evolution (Karlström 2004; Sandén 2004) and do not consider scenarios of use that include rebound effects and interaction effects. In a dynamic sustainability assessment, coproduction of impacts between a technology and its environment is to be included.

To summarize, there are a number of conditions that improve the validity of sustainability claims:

1. Present *objectified* information on the impacts of a technology.
2. Be attentive to different *perspectives* on technology, impacts, and sustainability.
3. Include *coproduction* of impacts between a technology and its context.

In a utopian world, sustainability assessments would be flawless on all three criteria. In Fig. 6.1, this sweet spot [S] is depicted at the intersection of the three

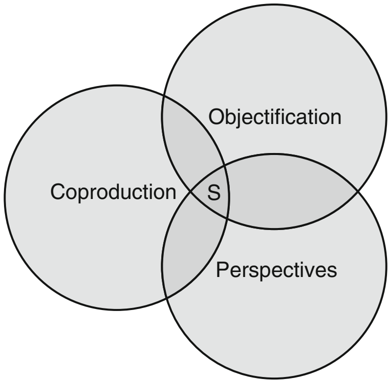

Fig. 6.1 Key conditions in sustainability assessment

Table 6.3 Conformity of assessment methods with key conditions of sustainability assessment

Assessment method	Condition		
	Objectification	Perspectives	Coproduction
Backcasting		X	X
Cost–benefit analysis	XX		
Dialogue methods		XX	
Ecological footprint (proxy methods)	XX		
Life-cycle assessment	XX	X	
Material flow analysis	XX	X	
Multi-criteria analysis	XX	X	
Scenario analyses		XX	X
Assessment procedural framework			
Environmental impact assessment			
Integrated sustainability assessment			
Strategic environmental assessment			

conditions of sustainability assessment. But then again, sustainability assessment would not exist in a utopian world, as we would all live in perfect harmony. Each assessment method has its strengths and weaknesses. This requires a practitioner to select strategically from the vast quantity of methods that are available. For each key condition, this chapter will illustrate its application in a practical sustainability assessment (Table 6.3).

2.1 *Objectification of Assessments: Life-Cycle Assessment*

Many methods can be identified that aim to objectify sustainability contributions. They are predictive and grounded in the paradigm of technical measurement (Guba and Lincoln 1989). Some widely used methods include cost–benefit analysis (CBA), ecological footprint, life-cycle assessment (LCA), material flow assessment (MFA), and multi-criteria analysis (MCA). This section will focus on **LCA** as a way to illustrate objectification in knowledge produced on the environmental performance of a technology (Box 6.1).

Box 6.1: A Life-Cycle Assessment of a Coal-Based Power Plant with Carbon Capture and Storage Facility

Koornneef et al. (2008) have conducted an LCA of a coal-based power plant with carbon capture and storage (CCS) facility.[2] An LCA consists of four stages: goal and scope definition, life-cycle inventory analysis, life-cycle impact assessment, and interpretation of results. The goal and scope definition states the main question that the assessment tries to answer: what environmental trade-offs and benefits result from CCS? Greenhouse gas emissions are central in this assessment, as they determine the allocation of CO_2 credits upon which CCS is financed. The specific technologies assessed are a post-combustion coal power plant CCS facility with a monoethanolamine solvent and two reference cases without CCS. For each case, the life cycle of the facility is addressed from cradle-to-grave. The assessment uses a functional unit of 1 kWh of electricity generated at the power plant (Koornneef et al. 2008).

In the life-cycle inventory analysis, the assessment provides an overview of environmentally relevant flows for key air pollutants, emissions to water, resources, wastes, and byproducts in metric units per kWh. Examples of inventory results are 200 g CO_2 per kWh and 67.97 mg nitrate per kWh for the facility with CCS (Koornneef et al. 2008). In the life-cycle impact assessment stage, "raw results" from the inventory analysis are analyzed to make statements on the actual impacts of environmental loads. After having obtained the results, a number of tests are conducted to establish their robustness. In this case, a sensitivity analysis is performed for a number of parameters to estimate the impact of deviations in key data or assumptions – such as the impact of changes in CO_2 removal efficiency on other impact categories (Koornneef et al. 2008).

The assessment concludes that, due to CCS, greenhouse gas emissions are reduced to 243 g/kWh. This is 78 and 71 % lower compared to the two reference plants without CCS. However, the assessment shows that CCS does lead to increases in the other categories, i.e., human toxicity, ozone layer depletion, freshwater eco-toxicity potential, eutrophication, acidification, and photochemical oxidation potential (Koornneef et al. 2008).

[2] Carbon capture and storage (CCS) can be defined as "a process consisting of the separation of CO_2 from industrial and energy-related sources, transport to a storage location and long-term isolation from the atmosphere. […] an option in the portfolio of mitigation actions for stabilization of atmospheric greenhouse gas concentrations" (IPCC 2005).

Regardless of results, an assessment as described in Box 6.1 cannot by itself make a valid sustainability claim. To determine a sustainability contribution requires a judgment on the value of a reduction in greenhouse gas compared to increases in other pollutants. Such judgment cannot be based on scientific knowledge alone but depends as well on notions about what is valued in nature. In LCA, such subjective elements are to some extent incorporated by different impact assessment methods (Baumann and Tillman 2004).

Beyond valuing outcomes differently, there are other aspects to assessment that matter. Review studies on LCA of CCS show that results depend primarily on the boundaries of the technology studied and choices regarding other system boundaries, type of impacts, method of valuation, and weighting (Corsten et al. 2013; Marx et al. 2011). The importance of such methodological choices is well recognized within the LCA community (Baumann and Tillman 2004; Finnveden et al. 2009). However, they are not confined to LCA but have to be made when using any assessment method.

Different assessment communities address these decisions differently. Generally, choices are made based on the goal of the study, traditions within a research community, knowledge of the assessor, funding, and so on. Principally, they are a matter of competing perspectives and interests. The LCA community has responded to such normative flexibility by developing guidelines to harmonize practices, demanding critical reviews of comparative studies leading to statements disclosed to the public, and a general call for transparency (Baumann and Tillman 2004). Such procedural streamlining is one option but does not dissolve differences. For a method that aims to present objectified results, such variety presents a fundamental problem.

2.2 Perspective-Based Assessment: Dialogue and Backcasting

Some assessment methods address the problem of perspectives head on and focus on values, interests, and power. They include dialogue approaches and certain scenario methods. Examples of scenario-oriented methods include forecasting, backcasting, and sensitivity analysis. Dialogue methods contain the Delphi method, focus group, and consensus conference. Box 6.2 illustrates a perspective-based assessment that explores contributions of hydrogen to a future sustainable energy system. Methodologically, it focuses on *backcasting* and *dialogue groups*.

Box 6.2: Backcasting with Dialogue Groups for Contributions of Hydrogen to a Sustainable Energy System

Hisschemöller and Bode (2011) have conducted an assessment of possible sustainable uses of hydrogen in a future energy system in the Netherlands. In the project, 60 stakeholders were involved over a 4-year period. Different perspectives on the use of hydrogen were integrated. Specific visions were developed for transport, construction, and energy (natural gas) infrastructure. Two methods used in the assessment were a dialogue approach and backcasting (Hisschemöller and Bode 2011).

(continued)

Box 6.2: (continued)

Dialogue was identified as a methodology for enabling problem structuring, stimulating the expression of different viewpoints, and allowing for interaction between those viewpoints. This includes the selection of a broad range of stakeholders with divergent perspectives, articulation of perspectives, confrontation of views and knowledge claims, and synthesis (Hisschemöller and Bode 2011). Backcasting was used to stimulate the development of different visions. It considers boosting creativity by freeing stakeholders from current mental and institutional restrictions. The method stimulates participants to articulate different perspectives and build arguments to support those perspectives (Hisschemöller and Bode 2011).

One of the conclusions in the transport perspective was that hydrogen in combination with fuel cell vehicles has the potential to contribute to inner-city air quality. H_2 is to be produced from natural gas at large industrial plants and distributed on a dedicated H_2 grid. This perspective assumes that natural gas will be cheaper than oil and that battery electric transport will not pick up due to range issues and the environmental risks of batteries. Its use in the built environment is mainly driven by user wishes to increase autarky from the central electricity grid. Here, hydrogen offers a promising future as a decentralized generation option. Surplus energy from intermittent renewables is converted to H_2 through electrolysis. This perspective assumes that hydrogen and non-hydrogen options can be complementary and an institutional environment that favors small-scale over large-scale energy generation. It would also require the development of local heat grids and storage options. From the energy infrastructure perspective, climate change is undergirding hydrogen visions. H_2 is envisioned to be mixed with natural gas into Hythane and transported through the existing natural gas grid. This vision depends on the development of efficient extraction technologies to extract H_2 from the Hythane mix at the end user. A constant supply of hydrogen and gas is required to balance flows in the grid (Hisschemöller and Bode 2011, pp. 16–20).

It is concluded that H2 is “potentially promising for the future.” A policy of diversification and niche development is proposed to stimulate different perspectives to develop in a protected environment (Hisschemöller and Bode 2011, p. 22).

Ignoring multiple perspectives makes the analysis one-sided by drawing on one single perspective that the assessor decides to adopt. Acknowledging different angles to a problem and solution increases the visibility of different perspectives and can stimulate mutual understanding. At the same time, it can also require the assessor to engage in the power struggle between incompatible perspectives. Depending on the need and desirability of integrating perspectives, the assessor will have to balance the number and types of perspectives to include. Including all perspectives would make the picture more realistic but also infinitely complex. Adopting too few perspectives prohibits valuable knowledge from entering the assessment. Also, the assessor will have to determine how to deal with the interaction between perspectives. It is possible to search explicitly for consensus but also to try to stimulate and manage conflict.

2.3 Coproduction of Impacts: A Search for Methods

Innovative technologies have effects that are beyond their direct impact. The impacts of technologies are coproduced by different actors through multiple and complex causal chains (Rip and Kemp 1997). Trying to assess the effect of a technological innovation in a system becomes complex very quickly. This can make it wise not to aim for prediction but for understanding and to base predictions on complex system dynamics. By including different feedback processes, the assessor can obtain rough estimates of impact (Sandén 2013). Well-known examples of feedback processes are economies of scale and increased user utility with diffusion (Andersson 2001; Rosenberg 1982; Utterback 1994).

Box 6.3 illustrates the *Socratic method*, an attempt to integrate the concept of coproduction with conditions of objectification and perspectives.

Box 6.3: A Socratic Method for Sustainability Policy Appraisal
Kemp and Weaver (Weaver and Kemp 2012) propose to consider the coproduction of effects in their assessment of policies or innovations that purposely intend to make a positive sustainability contribution. Instead of analyzing the question, "What are the likely impacts of this policy/innovation?," the following question is being asked: "Under what conditions could this policy/innovation contribute to sustainability and in which ways?"

With a Socratic dialogue, the authors propose a consideration of underlying values and assumptions together with causal linkages. This method requires the involvement of experts that have an understanding of various disciplines and are recognized as such. The Socratic method draws on expert knowledge about problems and causal links and considers value-based perspectives and coproduction aspects. The group of experts will engage in a series of discussions and dialogues aimed at getting a better understanding of a number of critical conditions for the sustainability contributions of a policy or an innovation in a system.

> The Socratic method draws on [1] foresight by examining technology evolution, [2] soft system methodology by considering causal links and different understandings of a problem situation, [3] environmental science in giving attention to material streams and environmental pressures, and [4] a sociotechnical perspectives on innovation, which views impacts of technologies as co-produced. (Weaver and Kemp 2012, p. 8)

(continued)

Box 6.3: (continued)

In an illustrative case study, Weaver and Kemp emphasize some interaction effects for the case of electric cars. A positive interaction effect occurs when electric cars are used involving park-and-ride and becomes the favored car of use in multicar households. It is also found that electric vehicles can stimulate the deployment of renewables by charging at off-peak times and providing storage for peak demand. A negative spillover effect of better batteries is the replacement of normal bikes by e-bikes in bike-using countries. In non-bike-using countries, the e-bike may substitute for motorized transport as a positive effect. There are also interaction effects with the grid (Weaver and Kemp 2012, p. 19). A consideration of these interaction effects may help to maximize positive benefits and reduce negative effects.

The Socratic method shows that including conditions of objectification, perspectives, and coproduction in assessments can be done by a *combination of methodologies*. From an assessment perspective, it can be interesting to see which other combinations can assess the sustainability effects of technologies.

3 Conclusion and Outlook

Sustainability has multiple dimensions. This chapter wants to stress that there is an inherent element of subjectivity in sustainable development that needs to be acknowledged even when that development is, at heart, about improved states of the environment. Understanding of objectivity, subjectivity, and development can serve a more fruitful discussion about choices in sustainability. One way of doing so is by integrating the three identified conditions – *objectification*, *perspectives* and *coproduction*, – in assessments.

First steps in this direction have already been taken. For example, stakeholder-based LCA calls for the inclusion of multi-stakeholder groups in LCA practices (Thabrew et al. 2009). Such practice is an example of the integration of perspectives into objectification methods. Alternatively, hybrid LCA extends assessment practices to include environmentally extended input–output tables (Finnveden et al. 2009; Hawkins et al. 2006). This can constitute a first step in combining the condition of objectification with notions of coproduction.

Also theoretically, relevant contributions have been made on aspects of coevolution and micro–macro links. Dijk (2010) has created a coevolutionary framework to study the dynamics of technological innovations which combines elements that can be objectified, such as sales levels and efficiency rates, with subjective perspectives from individuals and organizations. A number of researchers have developed insights by combining system dynamics with environmental assessments of technological development (Hillman 2008; Karlström 2004; Kushnir 2012; Sandén 2004). Such contributions underline the importance of integrating conditions of objectification, perspectives, and coproduction. They provide a useful starting point for developing assessment practices for the sustainability contributions of technologies.

Questions

1. What are the three key conditions for sustainability assessment of technological innovations?
2. In which ways do these three key conditions differentiate from each other? You are encouraged to use the examples of assessments in Boxes 6.1, 6.2, and 6.3 to illustrate your answer.
3. What condition for sustainability assessment do you have most experience with in your daily routine? Can you explain in which ways the other two conditions are/can be of importance?

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Database with short overviews of different sustainability assessment methods developed in a collaboration between universities led by Free University Amsterdam (VU). http://www.ivm.vu.nl/en/projects/Archive/SustainabailityA-test/index.asp

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