Chapter 12
Assessment of Different Bioenergy Concepts in Terms of Sustainable Development

Swantje Eigner-Thiel, Meike Schmehl, Jens Ibendorf, and Jutta Geldermann

Abstract This chapter focuses on the assessment of different concepts' sustainability regarding the energetic use of biomass in rural areas. The aim is to provide decision support, while taking environmental, economic, social, and technical perspectives into consideration. Possible (technical and organisational) concepts include biogas plants operated by electric service providers, a single biogas plant owned by a farmer, or bioenergy villages owned by a village cooperative. We describe the development of suitable ecologic, economic, social and technical criteria to assess the sustainability of different concepts and the adaption of existing indicator systems to the special requirements of sustainable biomass use for energy. The results of this sustainability assessment illustrate the different biomass concepts' advantages and disadvantages, which are compared by means of multi-criteria decision analysis methods. This decision support tool faciliates the decision process for mayors, district administrators, farmers and investors, who have to choose the most sustainable concept for a certain area. Furthermore, the sustainability assessment of bioenergy concepts has specific requirements with regard to their visualisation if such an assessment is to support the decisions of interested stakeholders in communities.

S. Eigner-Thiel (✉)
Interdisciplinary Center for Sustainable Development, University of Göttingen, Goldschmidtstr. 1, Göttingen D-37077, Germany

HAWK – University of Applied Sciences and Arts Göttingen, Büsgenweg 1a, D-37077 Göttingen, Germany
e-mail: eigner-thiel@hawk-hhg.de

M. Schmehl • J. Geldermann
Department of Production and Logistics, University of Göttingen, Platz der Göttinger Sieben, 3, Göttingen D-37073, Germany
e-mail: Meike.Schmehl@wiwi.uni-goettingen.de; geldermann@wiwi.uni-goettingen.de

J. Ibendorf
Interdisciplinary Center for Sustainable Development, University of Göttingen, Goldschmidtstr. 1, Göttingen D-37077, Germany
e-mail: jibendo@gwdg.de

H. Ruppert et al. (eds.), *Sustainable Bioenergy Production - An Integrated Approach*,
DOI 10.1007/978-94-007-6642-6_12,

Keywords Bioenergy concepts • Multi-criteria decision analysis (MCDA) • Social criteria • Sustainable development • Visualisation

12.1 Introduction

The use of biomass to produce energy is gaining increasing attention from policy-makers, energy supply companies and the public (Edenhofer et al. 2011; BMU 2009; Leitl 2007). There are several reasons for this: Owing to bioenergy's potentially lower carbon dioxide emissions, it is expected to contribute less to climate change than fossil energy resource use. Furthermore, using biomass to produce energy could preserve fossil energy reserves. In addition, bioenergy is the only renewable energy source that addresses all three energy sectors: the supply of electricity, heating/cooling and fuels for transportation (Vis et al. 2008). Fourthly, it can support rural development by giving farmers an alternative source of income besides food production, and – in the case of bioenergy villages – by involving villagers in direct democracy (i.e. via their participation in the decision processes in their village or district) and giving them a satisfying sense of community (Eigner-Thiel 2005). Finally, by using local biomass to produce energy, the domestic energy supply should be stabilised, thus reducing dependency on other – potentially political unstable – countries for the import of energy resources (oil, uranium, natural gas, etc.) (IEA 2004; Van Loo and Koppejan 2008).

Nevertheless, discussions on the sustainable development of biomass use to produce energy, do not only mention the positive effects. There are also concerns that the use of monocultures will increase due to a higher demand for energy crops, which could result in massive land use changes to accommodate high-productive crops such as maize.

Currently, the use of maize to produce energy has resulted in heated discussions. In addition, this could increase transport activities in rural areas, which would worsen the air pollution and lead to unwanted disturbances. Another critical point is energy plants' direct emissions, such as particulate matter and sulphur dioxides, which could be hazardous to human health. The designation of areas for energy crop production is also highly controversial. The ethical aspects of converting food production, nature conservation or grassland areas for the production of energy crops will lead to criticism, as will the environmental effects of direct and indirect land use changes (e.g., more carbon dioxide emissions due to the ploughing of grassland and a reduction in the biodiversity) (Jessel 2008; Fritsche et al. 2009).

In the meantime, several concepts for biomass use for energy, such as individually or collaboratively organised biogas plants or large-scale plants, have been realised or planned in Germany. These types of concepts are the main focus of the analysis in this chapter. However, economic, ecological and social aspects should be considered when following sustainable development principles (for our definition of sustainable development, see Sect. 12.3). Therefore, the decision process concerning the type of bioenergy plant and its dimensions has become increasingly complicated. Multi-criteria decision models may need to be applied to arrive at optimal agreements (Buchholz et al. 2009; Oberschmidt et al. 2010). The crucial management of considerable amounts of diverse data is linked to the decision model. The coordination of these data and their processing to arrive at different visualised results constitute a challenge because the data originate from different scientific fields (biology, physics, chemistry, geology, meteorology, psychology, social and economic sciences) that are not only extensive, but also time and space dependent (see Rautenstrauch 1999; Page and Rautenstrauch 2001). Thus, decision support methods should collect data from heterogeneous sources and condense them into different formats.

Many bioenergy supply concepts have been developed at a local scale in Germany over the past years. One of these is the idea of an energy self-sufficient village, which a group of scientists at the Interdisciplinary Centre for Sustainable Development (IZNE) at Göttingen University developed in 1998 (see Projektgruppe Bioenergie 2010, Chap. 2 in this book and in Box 12.1).

Box 12.1 Bioenergy Village Jühnde, Lower Saxony, Germany

In Germany, the bioenergy village concept has been around since 2000. The main aim of a village self-sufficient in energy is to have such a village produce at least as much electric energy as the residents and local industry need. The heat production should cover at least two-thirds of the village's demand. Another requirement is that the heat customers and the farmers providing the biomass should actively help plan the conversion of the village energy supply. With this idea in mind, the relevant scientists chose a suitable village in the Göttingen district as a pilot project from 17 other appropriate and interested villages. Thus, in October 2001, Jühnde was chosen as the model village. Jühnde has 780 inhabitants, nine farmers, an agricultural area of 1,300 ha and a forest area of 800 ha (Ruppert et al. 2008). Its advantage was that it was of a suitable size, which was of economic importance as the village was large enough to build a bioenergy plant that would be profitable. It was also socially important, since it was still small enough to ensure that everyone in the community could be kept informed. It was also a suitable area for biomass production as the village farmers were willing to use their land for biomass production. Moreover, it had a strong village community with many active associations, which spread the idea throughout the village and motivated enough households to participate in the project (Eigner-Thiel 2005).

After diverse planning stages (informing the inhabitants, closing contracts with the farmers and energy consumers, obtaining building and operating licences, etc.), construction began in 2001 and was completed in 2004. The technical concept's central component is the biogas plant in which microorganisms turn liquid manure and other wet biomass into biogas by

(continued)

Box 12.1 (continued)
means of wet fermentation. In the combined heat and power plant (CHP), the biogas is turned into electricity and heat. Electricity is fed into the public grid, and the heat is used to warm water, which the district's heating network pipes to the connected households. To cover the high demand for heat in winter, the plant is supplemented by a woodchip heating plant and an oil heating plant as contingency reserves.

Heat distribution in Jühnde began in September 2005. Today, 72 % of the households receive about 2,800 MWh of heat per year from the biogas plant. The remainder (approximately 1,500 MWh of heat per year) is supplied by the woodchip heating plant. The production of electricity is about 4,000 MWh per year, which the local energy supply company purchases. The Renewable Energy Sources Act (EEG) regulates the price of electricity.

Using biomass as a substitute for oil has had various impacts on the individuals, society, economy and ecology in Jühnde. The ecological benefit can be quantified as a 70 % per person reduction in the carbon dioxide emissions. After a financial deficit in 2005 when the plants were installed and started up, the operating company recorded a positive annual surplus. Since then, the heat customers (households) have saved approximately €800 per year. Psychological research has shown that those who were actively engaged in the planning process experienced the village community more profoundly as well as increased individual learning. Different methods of public relations, participatory planning and planning workshops were also realised and documented (Eigner-Thiel 2005, 2010). On the whole, Jühnde's inhabitants are very satisfied with the heat supply and the bioenergy village concept (Eigner-Thiel and Schmuck 2010; Ruppert et al. 2008; Ahl et al. 2007).

This example of a bioenergy village clarifies that planning a bioenergy village requires data from different sources. First, technical data on the bioenergy plant's output are required. In addition, each household's heat requirement has to be identified. Geographical data are also needed to identify suitable crops for the areas and to calculate the potential yields. Furthermore, economic data are required to calculate the investment and operating costs. For the realisation of a bioenergy village, social factors, such as people's motivation to engage in the planning process and the quality of the social networks are crucial, because as many people as possible should be involved and kept informed during all the planning stages. Without people's willingness, such a project cannot be implemented.

However, during the decision process for the optimal bioenergy concept, ecological, economic and social objectives were sometimes at loggerhead: One of the social aims was, for instance, to connect as many houses as possible to the bioenergy plant. From an economic perspective, this was not, however, always the best solution; for example, certain houses were too isolated from the others and too far away from the biogas plant (Eigner-Thiel and Geldermann 2009). These conflicts are indicative of all the other biomass paths: Each concept has its advantages and disadvantages. This is typical of complex decision situations when common sense becomes overburdened if a large number of criteria has to be considered. Here, multi-criteria decision analysis (MCDA) methods offer a way to structure the decision problem; therefore, this chapter will also show how this problem can be solved. Section 12.2 describes how MCDA works.

Why is MCDA needed for the choice between different biomass alternatives and why should these be assessed in terms of multiple sustainability dimensions?

Potential initiators of bioenergy projects draw on the limited experiences with existing bioenergy concepts. Diverse life-cycle assessment (LCA) studies were compiled after a methodological analysis of environmentally relevant material and energy flows for the use of biomass use for energy. However, natural scientists have criticised the assessment of the impacts, as the interrelationships are usually too complex to be modelled along linear impact factors. In addition, these studies do not show the impact on the affected local stakeholders, as economic and social perspectives as well as local aspects are usually underrepresented (see Hofstetter 1998; Kempener et al. 2009).

General sustainability criteria can initially be used to comprehensively assess the different bioenergy concepts pertaining to the economic, ecological and social aspects. However, their actual application may lead to very different and even conflicting results. Chapter 40 of Agenda 21 (BMU 1992) states that the usual indicators such as a country's gross national product or the unemployment rate do not sufficiently describe the status of sustainability development. Therefore, beyond the existing economic characteristics, further indicators should be developed to represent the three dimensions of sustainable development (economic growth, ecological protection and social equality) (see Box 12.3) as accurately as possible. There are, however, many indicator systems for assessing sustainable development (see, e.g., Breitschuh et al. 2008; Gamba 2008; Hoffmann 2007; Rösch et al. 2009; WBGU 2008).

Nevertheless, there are significant difficulties with defining such indicator systems, specifically if bioenergy's sustainable use needs to be assessed, as the possible indicators might not be precise, specific or comprehensive enough to reflect the local and regional developments' sustainability (see Heiland et al. 2003; Fleury 2005). After preliminary theoretical considerations of the definition and the formulation of sustainability criteria, actual significant and quantifiable criteria should be chosen for the specific area of biomass use for energy. Currently, there is no general system for specifying the indicators, due to the specificity and the complexity of the issues. Thus, besides an orientation towards the principles of sustainability (see Agenda 21, BMU 1992), it is crucial to describe the indicator system requirements transparently (e.g. see Reul 2002; Werheit 1996). Section 12.4 provides a description of our actual development of a criteria system.

First, sustainable development's increasing requirements – owing to the increasing awareness of the climate change impacts and the need for a reliable future energy supply system – mandate consulting interdisciplinary expert groups, who

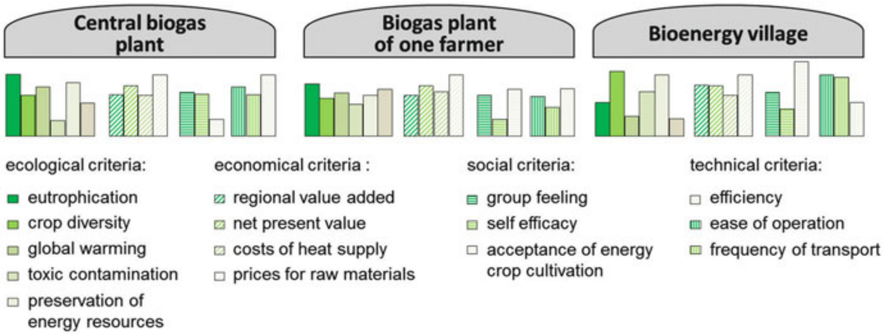

Fig. 12.1 Schematic presentation of conflicting targets of different bioenergy concepts

will take the numerous, and partly conflicting, objectives of and criteria for bioenergy assessment into consideration. General objectives, such as sustainability, economic viability and technical feasibility, have to be broken down into operational criteria that can be measured and are decision-relevant, i.e. that will allow one to distinguish between alternatives. In most decision situations, no dominating alternative meets all of the objective sustainable development criteria to allow it to be unanimously chosen from all the other alternatives. In fact, most of the alternatives have their strengths and weaknesses, but these are measured in different units; some kind of trade-off is therefore required. Figure 12.1 outlines a typical decision situation with regard to a central biogas plant, a farmer's biogas plant and a bioenergy village as examples of bioenergy concepts and the focus of this chapter; the bars' different heights show the various attributes' values within each concept's catalogue of criteria. The alternatives are described in some detail in Sect. 12.5.

Many aspects must be considered for a comprehensive assessment of the different biomass paths. Their varying priorities also need to be weighted, since not all of them are equally relevant.

First, absolute judgement span and immediate memory span impose severe limitations on the amount of information we are able to receive, process and remember (Miller 1956). Many aspects are considered during the process of balancing and condensing information,, which can quickly lead to a situation in which common sense no longer suffices (Dörner 2003; Vester 2003). The larger the number of people involved in a decision process in complicated situations, the more support is needed to objectively and efficiently arrive at decisions. Decision models with several objectives often describe reality better than models with only one objective. This has led to the development of numerous new approaches to multi-criteria decision support over the past 30 years (Figueira et al. 2005; Hwang and Yoon 1981; Yue and Li 1998; Munda 1995; Oberschmidt et al. 2009). In the theory of decision support and multi-criteria analysis, weighting (see Sect. 12.6) is one of the most disputed steps due to its relatively subjective character. However, decision trees and objective hierarchies can be used to operationalise ecological, economic, social and technical criteria and represent them in terms of certain attributes (e.g., their global warming potential).

12.2 Decision Support for Sustainable Biomass Use for Energy with Multi-criteria Decision Analysis (MCDA)

The MCDA framework is applied in research projects in this case to compare various concepts of bioenergy villages and alternative bioenergy supply solutions. This approach seeks to establish a decision support tool that increases the transparency of the decision process and lessens decision problems. However, with a minimum of technical and energetic effort, this tool should help those deciders who have to determine the most sustainable biomass concept for a certain area, as well as mayors, district administrators, farmers and bioenergy investors. We therefore outline the MCDA structure and describe the criteria development process. In addition, a comprehensive list of criteria is introduced and considered in Sect. 12.4.

The complex group decision process for sustainable biomass use for energy in a specific rural area can be simulated in an MCDA model.

The aim of MCDA is the ex ante assessment of a few individual options by explicitly considering a decision-maker's subjective preferences with regard to decision support and planning (monitoring and control vs. planning and choice) (Belton and Stewart 2002).

MCDA has been widely applied in an environmental context but hardly in bioenergy contexts. In these contexts, Mustajoki et al. (2003) describe the usage of this method in lake regulation policy, Malczewski (1999) establishes a link between spatial approaches (GIS) and MCDA, while Buchholz et al. (2009) provide a comprehensive overview of MCDA's application in the context of bioenergy.

The MCDA process can be divided into six steps, which might be somewhat iterative and interdependent due to the growing insight into the underlying decision problem:

1. Define and specify the overall objective in some detail in the criterion hierarchy.
2. Compile alternatives that can meet the defined objective.
3. Model and process information – investigate and calculate the values of the attributes (lowest-level criteria) (see Fig. 12.2 below) for the alternatives.
4. Assign a relevant weight, i.e. depending on each attribute's relevance, assign weights to certain values.
5. Calculate the results with operations research methods (MCDA algorithms).
6. Make the results visible with graphs and charts to assess the alternatives, then choose one.

Accordingly, the formulation of the overall decision objective is the starting point of decision support. In most cases, the overall objective is very general ("sustainable biomass use for energy") and needs to be broken down into operational attributes. A criterion hierarchy (see Fig. 12.2) shows the top-down approach. It starts with the overall objective (sustainable biomass use for energy) and expands this by adding more detailed targets, which should cover all the ecological, economic, social and technical aspects adequately without creating redundancy. Below the targets, there are attributes; these can operationalise the objective on an ordinal or cardinal scale (Belton and Stewart 2002).

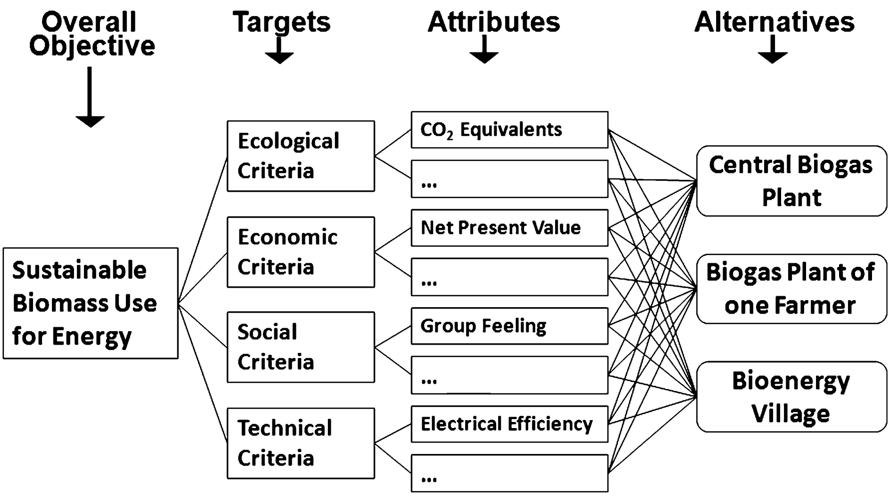

Fig. 12.2 Criterion hierarchy of sustainable biomass use for energy

In our case, the different concepts for biomass use for energy will be assessed according to the primary objective "sustainable development".

The MCDA process and the compilation of the criteria hierarchy are iterative actions; therefore, the criteria development procedure presented in this chapter is only a preliminary one. Nevertheless, the information development procedure is already applicable and we therefore demonstrate this procedure here.

12.3 Definition of Sustainable Development

A suitable definition is required to assess the different bioenergy alternatives' effects on sustainable development. There are many different definitions of sustainable development. The most popular is the one by the Brundtland Commission (United Nations 1987), the World Commission on Environment and Development (WCED): "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (p. 43).

The definitions that UNCED (1992) and the Helsinki Conference (1993) used highlighted three issues as the cornerstones of sustainability. According to these definitions, for development to be sustainable, it must be economically profitable, biologically proper and socially acceptable.

To assess a sustainable development issue, the concept must be broken down into single indicators or criteria. Some definitions only refer to ecological aspects (e.g., the indicator system SCOPE (1995)). The most comprehensive indicator system, which also considers social and economic aspects, is the UN Commission's sustainable development (CSD) indicator system. With its approximate 130 indicators, it is also a good foundation for the comparison of bioenergy concepts – but nothing more, as not all of its indicators are useful for our aim. For example, one of the indicators is that child labour should be avoided, which is obviously not applicable in Germany's biomass sector.

The EU set a minimum sustainable standard for biofuels with the Renewable Energy Directive (European Parliament 2009). This focuses on ecological aspects, seeks to reduce greenhouse gas emissions and tries to ensure that the biodiversity will be maintained. Social criteria are only mentioned in relation to the production of biofuels in developing countries and not with regard to biomass use in industrial countries like Germany. The criteria mentioned reflect the world's different agricultural situations, which are not totally applicable to a comparison of the different biomass concepts in Germany. However, the Directive has already been converted into legislation in different European countries, including Germany (BioSt-NachV 2009). The relevant criteria therefore need to be defined in greater detail.

In the scientific literature, a distinction is made between strong and weak sustainability: Weak sustainability means that a single dimension's value can be substituted by another (e.g., high economic values can substitute low ecological ones), whereas strong sustainability means that no substitution is possible between dimensions (Ott 2003; Wuppertal-Institut für Klima, Umwelt, Energie 1997; Daly 1999).

In our approach, we refer to the Brundtland Commission's (1987) definition of sustainability and to the sustainability concept comprising the three aspects economic growth, environmental protection and social equality (UNCED 1992; see Box 12.2) because they form a good basis for breaking down the concept into different categories. The technical dimension was added to the ecological, social and economic dimensions to enhance criteria development and assessment transparency, because the technical conversion of biomass is one of the distinct criteria for assessing different bioenergy concepts. In addition, the strong sustainability definition was chosen for the comparison of bioenergy concepts due to its above-mentioned benefits.

We break the sustainable development concept down into different criteria, which are addressed in the following section. We fill first apply the criteria to the assessment of three concrete alternatives described in some detail in Sect. 12.5.

Box 12.2 The Brundtland Commission (1987)

The increasing deterioration of the human environment and natural resources led the former UN Secretary General to appoint Gro Harlem Brundtland as chairman of The Brundtland Commission (formerly the World Commission on Environment and Development (WCED)) in 1983. The purpose of the The Brundtland Commission was to rally countries to pursue sustainable development together. Gro Harlem Brundtland, a former Prime Minister of Norway, was chosen to head the Commission due to her strong background

(continued)

Box 12.2 (continued)
in the sciences and public health. After releasing the Brundtland Report in October 1987, the Brundtland Commission was officially dissolved in December 1987. The organisation Centre for Our Common Future was founded in April 1988 to replace the Commission.

The Centre for Our Common Future seeks to create a united international community with shared sustainability goals by identifying global sustainability problems, raising awareness about them, and suggesting the implementation of solutions. Its report – *Our Common Future* – strongly influenced the Earth Summit in Rio de Janeiro, Brazil in 1992 and the third UN Conference on Environment and Development in Johannesburg, South Africa in 2002. It is also credited with creating the most prevalent definition of sustainability: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (p. 43). The three main pillars of sustainable development are economic growth, environmental protection and social equality.

12.4 Compiling a Criterion List

Although our introduction refers to indicator systems (e.g., see Breitschuh et al. 2008; Gamba 2008; Hoffmann 2007; Rösch et al. 2009), the present approach uses the term ‘criteria’, because the aim is not to compare the same aspect over time (which is usually the aim of an indicator system), but to compare different kinds of biomass paths at a single point in time, which is a fairly static approach.

From the different disciplines’ perspectives, the bioenergy concept’s evaluation criteria were collected from experiences gained with local bioenergy projects (mainly the bioenergy village Jühnde project and other village projects in the Göttingen district in lower Saxony; Projektgruppe Bioenergiedörfer 2010; Ruppert et al. 2008), from the literature and from discussions with experts (project-internal and project-external experts).

Moderated discussions were organised to collect criteria from different expert groups:

- ecology experts: geographers, earth scientists, agronomists, soil scientists, forestry scientists and plant scientists;
- economy experts: business administration, agricultural economists and industrial engineers;
- social aspects experts: psychologists and sociologists;
- technical experts: practitioners and scientists with bioenergy experience.

The greatest challenge of collecting criteria was to make everybody in the discussion groups understand that a criterion is only decision-relevant if its parameter value differ from comparative alternatives. The comparison of various bioenergy concepts would focus on special preconditions for agricultural land, because each region has special underlying basic geographical and socio-cultural conditions. These can include:

- temperature
- precipitation
- soil type
- social traditions
- price of the land

Since these preconditions cannot be changed in one location and cannot distinguish between the different concepts, these criteria are not decision-relevant. However, these preconditions influence the criteria specifications.

The implemented workshops to collect and weight the criteria (see Sect. 12.6) allowed for an iterative definition of the relevant decision criteria. If one of the scientific disciplines found a more significant criterion, or an easier-to-measure criterion, the criteria hierarchy was adjusted accordingly. The moderation of the groups guaranteed effective structuring, systematic management as well as the decision-making process's transparency. This would ensure that all the experts possessed the same level of information. Nevertheless, during the interdisciplinary discussions, difficulties were experienced with understanding what certain people really meant, even *within* one discipline. After many discussion forums, the relevant data and information were presented as a hierarchy of criteria. This hierarchy's structure and organization form the basis of a systematic and quantitative assessment – a decision table.

The following criterion list was drawn up to assess the sustainability of bioenergy alternatives (see Tables 12.1, 12.2, 12.3, and 12.4). As it is a work in progress, this list has a preliminary status. Decision support is an iterative process, and changes in the criteria hierarchy are thus to be expected when the decision table, with all the criteria scores, is completed. In the following, the ecological, economic, social and technical criteria are introduced and explained.

12.4.1 Ecological Criteria

Nature conservation refers to the protection of the ecosphere from negative impacts by human activities, including the use of biomass for energy. These have effects on the quality of the environmental media, i.e. the air, soil and water, as well as on the non-renewable resources and biodiversity. To quantify these impacts on the environment, methodological impact assessment approaches can be used as part of the life-cycle assessment (Guinee et al. 2002; Geldermann et al. 1999). Suitable impact categories and their characterisations are found in, for example, Schmitz and Paulini (1999) or SETAC (1996). The methodology of life-cycle assessment involves considering the entire product life-cycle. The impact assessment of a bioenergy concept should also include resource extraction, the agricultural production of biomass and its conversion into energy. Several studies have therefore

Table 12.1 Ecological criteria related to biomass concepts

Ecological targets 	Sub-targets	Attributes	Unit	Manifestation of the attribute for sustainable development (Min./Max.)
(1) Air and climate	(1.1) Climate change	Global warming potential	kg CO_2 equivalents	Min.
	(1.2) Toxic contamination	Mass of respirable particulate matter	kg PM_{10}	Min.
		Mass of benzo(a) pyren	kg benzo(a) pyren	Min.
		Mass of inorganic reference substance	kg of inorganic reference substance	Min.
	(1.3) Acidification	Acidification potential	kg SO_2 equivalents	Min.
(2) Water	(2.1) Aquatic eutrophication	Mass of applied fertiliser – nitrogen	kg fertiliser – nitrogen	Min.
		Mass of applied fertiliser – phosphor	kg fertiliser – phosphor	
	(2.2) Toxic contamination	Mass of applied pesticides	kg pesticides	Min.
(3) Soil	(3.1) Erosion	Cultivation method	Points on ordinal scale	Min.
		Land cover level	%	Max.
	(3.2) Terrestrial eutrophication	Mass of applied fertiliser – nitrogen	kg fertiliser – nitrogen; kg fertiliser – phosphor	Min.
		Mass of applied fertiliser – phosphor		Min.
	(3.3) Soil contamination	Accumulation of heavy metal reference substance	kg mobilised reference substance	Min.
		Mobilisation of heavy metal reference substance	kg mobilised reference substance	Max.

(continued)

Table 12.1 (continued)

Ecological targets 	Sub-targets	Attributes	Unit	Manifestation of the attribute for sustainable development (Min./Max.)
(4) Preservation of resources	(4.1) Energy	Scarcity of energy ressources	kg crude oil-equivalents resource	Min.
		Cumulative energy demand	MJ	Min.
	(4.2) Minerals	Demand for phosphate	kg phosphate	Min.
	(4.3) Land area consumption	Demand for space	m^2	Min.
	(4.4) Water consumption	Demand for water	m^3 water	Min.
(5) Protecting biodiversity		Quantity of cultivated crops	Quantity	Max.
		Mass of applied pesticides	kg pesticides	Min.
		Nitrogen fertiliser type	Points on a ordinal scale	Min.

Table 12.2 Economic criteria related to biomass concepts

Economic targets 	Attributes	Unit	Manifestation of the attribute for sustainable development (Min./Max.)
(1) Operating company's perspective	Net present value	€	Max.
	Supply contract duration	Years (points)	Max.
(2) Employee's perspective	Profit sharing	Yes/no (points)	Max.
	Possibility of additional fee	Yes/no (points)	Max.
(3) Heat clients' perspective	Annual heat supply costs	€ per year	Min.
	Minimum deposit	€	Min.
	Connection and conversion fee	€	Min.
(4) Farmer's perspective	Input in pricing	Points	Max.
	Operational flexibility	Per year one point	Max.
(5) Regional perspective	Regional value added (investment)	% of the investment sum	Max.
	Regional value added (current)	€	Max.
	Tax revenue	€	Max.

Table 12.3 Social criteria related to biomass concepts

Social targets 	Attributes	Unit	Manifestation of the attribute for sustainable development (Min./Max.)
(1) Acceptance	Cultivation concept scenery (aesthetics)	Points	Max.
	Scenery of the technical plants (aesthetics)	Points	Max.
	Smell	Points	Min.
	Noise (factory)	Points	Min.
	Noise (transport)	Points	Min.
(2) Participation	Planning	Points	Max.
	Information	Points	Max.
	Decisions concerning finances	Points	Max.
(3) Psychological effects	Feeling of independence from electricity supplier	Points	Max.
	Feeling of independence from fossil energy	Points	Max.
	Solidarity	Points	Max.
	Self-efficacy	Points	Max.
	Pride, fun, meaning	Points	Max.
	Image of the village	Points	Max.
	Assessment of accidents	Points	Min.
(4) Employment	Additional workplaces	Number	Max.
	Possibility to work part-time	Points	Max.

Table 12.4 Technical criteria related to biomass concepts

Technical targets 	Attributes	Unit	Manifestation of the attribute for sustainable development (Min./Max.)
(1) Plant efficiency	Thermal efficiency factor	%	Max.
	Electrical efficiency factor	%	Max.
	Use of heat in summer	Yes/no (points)	Max.
	Modularity	Points	Max.
(2) Transport	Frequency	Points	Min.
	Point in time	Points	Min.
(3) Administrative effort	Duration of licence	Days	Min.

analysed the environmental effects of bioenergy product chains (Roedl 2010; Fritsche et al. 2009; Kimming et al. 2011; Schmehl et al. 2012).

The list of ecological criteria below were presented by Weber-Blaschke et al. (2002). These criteria describe recent environmental indicator systems and identify various structures according to their environmental media, problem areas, sectors, spatial dimensions and socio-economic indicators.

In this study, the first level of the ecological criteria's hierarchy is structured according to the environmental media and resources. The subordinate criteria level lists the associated problem areas (see Table 12.1), which are quantified by attributes at the bottom level. Firstly, the decision-relevant criteria are briefly explained. Table 12.1 summarises the set of ecological criteria with their units of measurement.

(1) Air and climate

The emission of specific substances into the air contributes to climate change, has toxic effects on humans, animals and plants, as well as acidifying effects on terrestrial and aquatic ecosystems. The impact categories ozone depletion and photochemical ozone creation are not yet considered in the context of this study. The main origins of these environmental issues are chlorofluorocarbons and hydrocarbons, whose emission is estimated as not relevant for the comparison of different bioenergy product chains.

(1.1) Climate change

At present, climate change is one of the most discussed environmental issues. Although potential individual impacts on humans and ecosystems have been analysed in different studies (Hughes 2003; Thuiller et al. 2011), the entire extent of the future effects have not yet been estimated.

Global warming potential is one commonly accepted indicator with which to quantify emitted greenhouse gases' contribution to climate change. Recent indicator values for greenhouse gases with a time horizon of 100 years are listed in the IPCC (2007), which considers the emissions of all greenhouse gases from the bioenergy chain's life-cycle. The target is to minimise the global warming potential.

(1.2) Toxic contamination of the air

The burning of solid biomass – which is, for example, part of the bioenergy village concept – causes emissions with potentially toxic effects (Ferge et al. 2005); therefore, the conversion process is used to assess the degree of air contamination. Since our study cannot carry out a detailed exposition analysis, the assessment is restricted to the following three attributes (see also Chap. 14):

(a) Particulate matter

Particulate matter has a dusty and gaseous nature and is thus a potential risk for living organisms' health. An increased concentration of particulate matter can lead to respiratory and cardiovascular diseases in humans and to a high mortality rate. The sources of particulate matter are: industrial processes, road transport and the burning of biomass. PM_{10} (particles with an aerodynamic diameter smaller than 10 μm), which characterises respirable particulate matter, has commonly been used as an indicator of particulate matter in the air (Hewitt and Jackson 2003; World Health Organization 2006). Therefore, PM_{10} has been chosen as a suitable attribute of particulate matter within the bioenergy process chain.

(b) Organic pollutions

The working group of the German Research Center for Environmental Health analyses the hazardous organic substances emitted in the biomass burning process and has identified Benzo(a)ypyren as a reference parameter that might be cancer-causing (Lenz 2010) (see also Chap. 13). This reference substance is also taken as the attribute of organic pollutions in the MCDA.

(c) Inorganic pollutions

The inorganic pollutions due to the biomass burning process are analysed by colleagues in our research project (see Chap. 13). The group of inorganic pollutants includes heavy metals such as cadmium, arsenic and lead, which might also be carcinogenic (Lenz 2010). A reference substance has not yet been determined. A suitable attribute for assessing inorganic pollutions will therefore be added in the course of the project.

(1.3) Acidification

Several air pollutions such as sulphur dioxide, hydrogen sulphide, ammonia and other sulphur and nitrogen compounds react in an oxygen environment with acid and contribute, among others, to damage forests and lakes (Nixon et al. 2000). Although the environmental impacts refer to water and land, acidification criteria are not listed for these environmental media but for air as the origin of emission. Acidification is a commonly used impact category in life-cycle assessment. In line with de Haes (1996) acidification potential has therefore been chosen as an attribute.

(2) Water

Nixon et al. (2000) emphasise four significant water quality issues: eutrophication, persistent organic pollution of rivers, acidification (see above) as well as nitrate and pesticide contamination of groundwater. In this study, these issues are combined in two sub-categories of aquatic eutrophication and water contamination with persistent toxic substances. Since bioenergy chains do not seem to have significant effects on the organic pollution of rivers, this aspect is omitted.

(2.1) Aquatic eutrophication

Aquatic eutrophication is caused by nutrients that lead to increased algae growth. As a result of bioenergy chains, important nutrients, such as mineral fertiliser and manure, enter ecosystems by means of run-off in the agricultural process stage.

Within the outline of this study, it should be sufficient to consider minimising the mass of nitrogen and phosphor due to the application of mineral fertiliser and manure for biomass production as the criterion goal.

(2.2) Toxic contamination of water

In the context of bioenergy, there is a risk of toxic contamination of the groundwater through pesticide application during the energy crop cultivation phase. The higher the mass of pesticides applied for a special energy crop per area, the higher the risk of groundwater contamination and the less sustainable the bioenergy concept.

(3) Soil

Erosion is the main threat that the environmental medium soil – which includes soil life – faces; however, nutrient enrichment and heavy metal pollution have also been identified as threats (Bouwman et al. 2002; Rodrígues et al. 2008; Rusco et al. 2008). A further problem is agricultural soil compaction due to the use of heavy agricultural machines in cultivation. However, compaction is not expected to have an effect on different bioenergy concepts and it is consequently omitted.

(3.1) Erosion

Erosion leads to agricultural soil losing its functionality (Pimentel 2006). Besides site-characteristic factors, such as the soil texture, the precipitation regime and slope, agriculture management also plays a significant role (Kort et al. 1998; Lobb et al. 1999). The cultivation method and covering the land with crops are considered important soil stabilization factors.

(a) Cultivation method

There are several cultivation methods to prepare agricultural soil for sowing. All these methods increase the risk of erosion. In this study, three methods are defined: (1) direct saw, (2) grubbing, and (3) ploughing. Direct saw is considered the best and ploughing the worst regarding minimising the risk of erosion.

(b) Land cover level

Crops stabilise the soil and reduce the risk of erosion. The higher the land cover level throughout the year, the better the protection against erosion and the better the sustainability assessment.

(3.2) Terrestrial eutrophication

The deposition of aerial nitrogen compounds leads to increased vegetation growth accompanied by a decrease in biodiversity and the vegetation's increasing sensitivity to disease, drought, frost and herbivore increases (Gallego Schmid 2009). The same approach is used to calculate terrestrial eutrophication and aquatic eutrophication. The target is to minimise nitrogen and phosphor feeding by means of fertilisers.

(3.3) Soil contamination

Hazardous heavy metals affect soil, especially agricultural soil, which is the basis of life. In the bioenergy chain, the most relevant contamination source is fertiliser application (mineral fertiliser, digestate and manure) during the energy crop production phase. The fewer the heavy metals introduced into the soil through fertiliser, the better the sustainability assessment. In the context of this project, two aspects are relevant: the accumulation and mobilisation of heavy metals.

(a) Accumulation of heavy metals

The introduction of heavy metals through fertiliser is a criterion that represents heavy metal accumulation in soil. The fewer the heavy metals applied to agricultural soil, the less the risk of heavy metal accumulation.

(b) Mobilisation of heavy metals

Since potentially contaminated sites can also be considered for energy crops, heavy metal mobilisation is another attribute (see Chap. 14). Unlike amelioration activities, the removal of pollutants is not used in this project's assessment approach (see Chap. 14). As within the biogas chain, a minimum of heavy metals transferred to an energy crop ultimately leads to a low heavy metal content in the digester. The mobilised quantity of a specific heavy metal is quantified for each alternative bioenergy concept. The fewer the heavy metals mobilised, the better the bioenergy concept.

(4) Preservation of resources

The need for mineral and energy resources is an essential part of all industrial processes and should 'also be considered in bioenergy concepts. As these resources are finite and the principle of equal opportunities for future generations should be respected, resource consumption evaluation cannot be omitted from sustainability analysis. Given the particularly strong association of bioenergy with agricultural energy crop cultivation, further – renewable – resource types should also be covered; the resources land area and water also belong to this aspect.

(4.1) Energy

Energy resources can be classified as non-renewable and renewable. Renewable sources of energy are solar energy, hydropower, wind power, geothermal energy and biomass. Non-renewable resources can be divided into fossil energy (oil, gas and coal) and nuclear power.

(a) Scarcity of energy resources

The consumption of non-renewable fossil energy resources, such as oil, gas and coal, leads to a potential scarcity. Given the static range and specific calorific value, scarcity can be quantified with respect to crude oil as the tonnes of crude oil resource equivalent (Gromke and Detzel 2006; Monier and Labouze 2001; Schmitz 1995). The higher the crude oil resource equivalents' value, the higher the extraction effect.

(b) Cumulative energy demand

The cumulative energy demand (CED) is possibly an important characteristic value with which to evalute energy criteria. The CED is defined as the entire primary energy demand in Joule that can be allocated to an economic good's life-cycle (VDI 1997); in this case, the specific bioenergy path. The CED is often used as a screening impact indicator and can also be applied to distinguish between renewable and non-renewable energy demands (Fritsche et al. 1999; Huijbregts et al. 2006; Schmitz and Paulini 1999). The smaller the CED value, the better the assessment result.

(4.2) Minerals (demand for phosphate)

After discussions were held with ecology experts, the conclusion was that the analysis of the scarcity of mineral resources within bioenergy systems should concentrate on the consumption of phosphate as a fertiliser for energy crop cultivation.

Phosphate's scarcity is already a primary problem, especially in agriculture (Cordell et al. 2009). Therefore, the less phosphate is used for energy crop cultivation, the better this is for phosphate resource preservation.

(4.3) Land area consumption

Land area – especially in an unsealed and not built-up state – is a scarce good. Consequently food production, energy crop cultivation and nature conservation compete for it (DEIAGR 2008; Delzeit et al. 2010). As little space use as possible should therefore be assigned to bioenergy to reduce these land use conflicts.

(4.4) Water consumption

As a resource, water should be conserved – not only its quality, but also the quantity used for energy crop cultivation should be taken into consideration. The less water needed throughout a life-cycle, the more sustainable the bioenergy concept.

(5) Protecting biodiversity

Biodiversity is an important factor for a stable ecosystem (Millennium Ecosystem Assessment 2005); consequently, conserving the variety of life forms should be a relevant aspect in environmental assessments. During the project discussions, nature conservationists identified three parameters regarding a bioenergy path's contribution to biodiversity protection. All the parameters focus on agricultural production of bioenergy crops.

(a) Number of different cultivated crops

The first parameter is the number of different cultivated crops needed as a substrate input for a biogas plant. The larger the number of energy crops cultivated on arable land, the more positive their impact on biodiversity.

(b) Mass of applied pesticides

The mass of applied pesticides reduces the variety of living organisms in an agricultural area. Since a high amount of pesticides represses biodiversity, this parameter should be minimised with a view to sustainable development.

(c) Nitrogen fertiliser type

The nitrogen fertiliser type also has an effect on biodiversity. Providing the soil with nitrogen through cultivated legumes is considered better for biodiversity than digestive manure. On the other hand, digestive manure leads to a more active soil life than mineral fertiliser. This consideration leads to the following assessment points: cultivating legumes = one point; digestive manure = two points; mineral fertiliser: three points. The fewer points allocated, the better the evaluation.

The ecological criteria are presented in Table 12.1 below.

12.4.2 Economic Criteria

The broadest differentiation of economic criteria is into investments and operating costs: Investments are defined as the sum of all incurred expenses until plant operation readiness, while operating costs occur during operation and depend on the capacity utilisation (Geldermann and Rentz 2004). In our case, the following cost components need to be considered: investments (one-time), biomass (annual), wages (annual), transport (annual), interest on borrowed capital (annual), dividends for capital contributions (annual), repairs (annual) and miscellaneous (e.g., accounting, trade tax or bookkeeping; annual). Incoming payments result from electricity and heat sales (annual), sponsor funding (annual), residual value (one-time after 20 years, or after the expected plant lifetime).

To develop meaningful economic criteria for the bioenergy concept assessment, the following stakeholder group perspectives have to be considered:

- operating company
- employees
- heat clients
- farmers
- region.

The regional perspective reveals further aspects. Although there are many definitions of a region, and the region around a possible bioenergy village cannot be clearly defined (see Box 12.2), it affects all these stakeholder groups' interests plus those of their neighbours. It can also be referred to as the administrative department's perspective.

(1) Operating company's perspective

The operating company's corporate boundaries begin with biomass supply and end with electricity and thermal energy sales. The bioenergy plant owner can be a single investor, an investor group, or a village cooperative.

(a) Net present value

Net present value (NPV) is a key financial management indicator. An investment's NPV is the difference between the sum of the discounted cash flows expected from an investment and the initial amount invested. An interest rate is chosen to adjust for time and risk (see Chap. 10). The project with the highest NPV should be selected if the NPV is the only criterion.

(b) Supply contract duration

The longer the running time of the contracts between the operating company and the agriculture and forestry suppliers, the higher the operating company's planning security. The operationalisation was undertaken by means of points: running time 0–3 years = 0 points; 4–10 years = 1 point; 11–15 years = 2 points; >15 years = 3 points.

(2) Employee's perspective

The operating company employees are the plant manager, the operator, account staff and the unskilled workers. Their wage level is not part of this list, because it would not distinguish between the different technical and organizational plant forms in Germany.

(a) Profit sharing

If the employees participate in profit realisation, or if there are other incentive systems, this criterion is assessed positively (one point). If there is no possibility of profit realisation participation, it is assessed negatively (0 points).

(b) Possibility of additional fee

If there is the possibility for more people besides full-time employees to work at the plants on a fee basis, this criterion is assessed positively (yes = 1 point, no = 0 points).

(3) Heat clients' perspective

Heat clients are people whose homes are connected to the public hot water grid and who are associated with the operating company. In many considered bioenergy concept cases, this is a cooperative. The heat clients are interested in paying moderate prices for their heat.

(a) Annual heat supply costs

Different biomass energy paths have different price tags for their clients. In a bioenergy village (for the definition see Box 12.1 above), for example, people in connected households pay less for their energy than people using fossil fuel energy (the base is the mean of the basic charge and the heat price per kWh) (Ruppert et al. 2008). The lower the annual heat prices, the better for the clients.

(b) Minimum deposit

If people have the opportunity to participate in an operating company, for instance a cooperative, they have to pay a deposit. The lower the minimum deposit, the better for the clients, because the threshold for people to take this step is then lower.

(c) Connection and conversion fee (one-time pay-offs)

The lower the fee for connection, to the operating company, the conversion costs and deposit, the better this is for heat clients.

(4) Farmers' perspective

Farmers can have different roles in bioenergy projects: They can simultaneously be raw material suppliers who earn money with this and heat clients with an interest in getting heat at a low price. These are opposing targets.

(a) Influencing the price of biomass

If farmers involved in bioenergy plants can influence the price of biomass during the running contract, this criterion is assessed positively with 3 points on a 3-point scale. By having input in the pricing, these farmers can incorporate the agricultural market trend and avoid suffering financial setbacks that no other farmers encounter.

(b) Operational flexibility

The shorter a contract is, the greater the flexibility for farmers. The contract length is assessed by means of points: duration > 15 years $= 0$ points; 11–15 years $= 1$ point; 4–10 years $= 2$ points; < 4 years $= 3$ points.

(5) Regional perspective: Regional net product

The regional value added is the value at which the regional output is bigger than the input. In this case, it refers to the region within a radius of approximately 50 km around the bioenergy plant's location. Behind this is the assumption that, within this radius, all important technical crews and service contractors can be obtained.

(a) Regional value added (investment, one-time)

Examples of regional value added relate to the investment in engineers, in craftsmanship, or in the construction industry (civil engineering). The higher the sum of the regional value added for investment, the better for the region (see for a definition of a region Box 12.3).

(b) Regional value added (current)

Examples of regional value added concerning the scope of current issues are: maintenance and repair work, notary fees, insurance companies, raw materials from farmers, etc. The higher the regional value added for current issues, the better for the region.

(c) Tax revenue

The council and the administrative district obtain trade tax and income tax from the operating company. The higher these earnings are, the better for the region. The assessment takes place by means of points: 1 point if the council has such income; no point if there is none.

The economic criteria can be viewed in Table 12.2 below.

Box 12.3 What Is a Region?

"Region" is a very broad concept. Different authors and scientists use a range of definitions. Among others, the definition depends on the discipline: Natural scientists often rely on other definitions than social scientists do. For example, a classification can be divided into two aspects:

(a) functional assignments that are grown historically. Examples include:

- job market regions (connected by commuter streams)
- business market regions (the catchment area of single contractors).
- regions for nature protection (spatial links between single ecosystems)

Such classifications, which are dependent on functional coherences, are too imprecise to encompass a region's administration. Therefore, there is a group of:

(b) administrative regions:
NUTS (Nomenclature des Unites Territoriales Statistiques) makes provision for the following regions: states (0), federal states (I), districts (II) and communal districts (III). Regional aggregations (such as the Metropolregion Hannover) are not accounted for (NUTS 2007).

There is also the concept of a "region's identity", which comprehends a subjective "identity for the region", which can differ per individual in the same region (Ipsen 1993).

12.4.3 *Social Criteria*

Social criteria for assessing different bioenergy paths' sustainability can be divided into four sub-categories: acceptance, participation, psychological consequences and employment. Table 12.3 below contains the list of criteria.

(1) Acceptance

Chapter 28 of Agenda 21 (BMU 1992) addresses the participation of the council and people in order to solve environmental problems. Furthermore, to promote sustainable bioenergy use, the population's acceptance of the technical systems and the context of the production and logistics are extremely important. Bioenergy use acceptance refers to the following four aspects:

(a) Scenery of cultivation concepts (aesthetics)

Different cultivation concepts have different impacts on the landscape aesthetics: The landscape can be very colourful and heterogeneous if farmers practice crop rotation (such as triticale, rapeseed, rye and sugar beet, which are perhaps mixed with poppies and other weeds), whereas the scenery can, for example, be boring in the case of maize monoculture. The more positive people's response to a landscape's aesthetics, the better it is. The criterion is operationalised via a five-point scale. The higher the assessment, the better.

(b) Scenery of the technical plants (aesthetics)

Production plants (biogas plant, wood-fuelled heating plant) can also be assessed as either more or less aesthetically pleasing. The more positive this assessment, the better. The criterion is also operationalised via a five-point scale.

(c) Smell

When comparing biomass alternatives, we start with compliance with odour nuisance limit values. Nevertheless, there is a subjective smell regarding biomass use for energy supply (e.g., the storage of silage next to biogas plants, and the transport of liquid manure) and this can impact acceptance. It is important to note that this does not have to be an objective criterion, it can be the *perceived* or *suspected* smell related to biomass use in someone's imagination (it can also be a prejudice). The less the perceived stench, the better.

(d) Noise (factory and transport)

The block heat and power plant in the factory and transport (via truck or tractor) produce some noise. The larger the technical plant and the more biomass it requires, the greater the possibility that people will perceive the noise as annoying. Noise depends on perception: If the purpose of the noise is considered meaningful, it is assessed as positive and vice versa; consequently, this criterion is also subjective (Guski 2000). The less annoying the noise is perceived, the better. The noise is further categorised into perceived factory noise and perceived transport noise.

(2) Participation

Participation refers to different mechanisms through which people can express their opinions and, ideally, can exert influence on political, economic, management, cultural, family or other social decisions, to which the Agenda 21 action plan refers (BMU 1992, Chapter 28). From an administrative perspective, participation can build public support for activities. It can educate people about an agency's activities. Participation can also facilitate useful information exchange regarding local conditions. Furthermore, participation is often legally mandated. From citizens' perspective, participation enables individuals and groups to influence agency decisions in a representational manner (Girschner and Girschner-Woldt 2007).

In terms of diversity management, the following groups should be considered in the planning of biomass use and in the decision process:

- farmers
- heat clients
- men and women equally
- the communal and regional administration
- villagers and the general public
- nature conservationists
- scientists.

The more opportunities for stakeholders to participate, the better. Such participation can comprise different content aspects associated with different participation intensities. These aspects are described below.

(a) Participation in the planning process

People from the seven stakeholder groups can be involved in the planning and decision process for the use of a biomass concept. However, in different biomass concepts regard people's needs and wishes to a differing degree: The more people are involved, the more their wishes and anxieties can be considered and conflicts avoided. This can impact the local residents' satisfaction, self-efficacy, etc. (Eigner-Thiel 2005). The different biomass alternatives differ in the extent to which people are involved in their planning process. For example, as many stakeholder groups as possible should be involved in the planning process of a bioenergy village, while a large-scale plant offers less possibility for extensive involvement. The more groups involved, the better.

Since seven stakeholder groups were identified, participation in the planning process is assessed according to eight points. One point is allotted for each participating group and zero if nobody is allowed to participate. The more groups involved, the better.

(b) Participation via information

The lowest form of obtaining participation is simply by providing information. This can be done by means informational events or meetings, information brochures and flyers or stalls at festivities. It is important to inform people not only once about the status of a planning process, but regularly. The communication interval can differ between the biomass options (e.g., it is dependent on the operator type). The more stakeholder groups are informed, the better. Again, there are eight points according to which participation in the form of providing information is assessed. One point is assigned for each participating group and zero if nobody is allowed to participate.

(c) Participation in finance decisions

Biomass paths can be financed by a single investor, communal institutions or administrations, or groups of individuals (e.g., a cooperative). If individuals have the opportunity to contribute to the finances, this can have various positive consequences: First, this is an additional investment from the population. Individuals can also influence the usage of their investment (e.g., determining the price of heat and raw materials; this could include price corridors and upper and lower boundaries). In addition, being consulted can increase an individual's sense of self-efficacy. Finally, people who participate in the finances will receive (at least a small) financial gain, for example, in the form of lower heat costs, or participation in the profits. This means that biomass paths offering more stakeholder group participation in the finances can be considered more sustainable than those without this possibility. The higher the number of participating groups, the better. Again, there are eight points according to which the participation in finances is assessed. One point is allocated for each participating group, and zero if nobody is allowed to participate.

(3) Psychological effects

Different biomass options can have different consequences for people's self-perceptions through the different degrees that people are allowed to participate in the planning and decision processes. This means different degrees of sustainable development. For the study of these factors (data), see also Eigner-Thiel (2005) and Chap. 12 in this book.

(a) Feeling of independence from large electricity suppliers

If a bioenergy plant operator is a local – perhaps collectively organised – institution, the feeling of independence from large energy suppliers can be especially high. This is the result of many discussions in village meetings and interviews with people engaged in a bioenergy village (Eigner-Thiel 2005). The feeling of independence is assessed as more sustainable, because there is more self-reliance and less heteronomy concerning price determination, supply security and other important aspects of their lives, but also concerning accident risks. The feeling of independence is operationalised on a scale of 0–4. The higher the value, the better.

(b) Feeling of independence from fossil resources

If local residents know that their biomass-based heat source is renewable, the feeling of independence from non-renewable resources (such as fossil fuels, oil, natural gas, etc.) can grow. The assumption is that the higher the participation rate, the higher the awareness of this autonomy. The feeling of independence is operationalised on a scale of 0–4. The higher the value, the better it is.

(c) Sense of solidarity

This criterion is associated with the extent of the possible participation. Interviews indicated that active engagement in a collective climate protection project enhances solidarity in a group. This has positive effects on people's well-being and health (Eigner-Thiel and Schmuck 2010). The sense of solidarity is operationalised on a scale of 0–4. The higher the value, the better.

(d) Self-efficacy

Self-efficacy is the measure of one's competence to complete tasks and reach specific expected goals. This expectation influences one's thoughts, emotions, behaviour, ambition, effort and persistence (Bandura 1992, 1997). This criterion is also dependent on the extent of the participation, as indicated in interviews (Eigner-Thiel and Schmuck 2010). The feeling of self-efficacy is assessed on a scale of 0–4. The higher the value, the better.

(e) Feelings of pride, fun and meaning

There are also coherences between the degree of participation and the pride and joy at planning and implementation, learning success, satisfaction and a positive feeling of meaning. This relationship is described in interviews (Eigner-Thiel and Schmuck 2010; Wüste and Schmuck 2012). The feeling of pride, fun and meaning is operationalised on a scale of 0–4. The higher the value, the better.

(f) Image of the village or town

The existence of bioenergy technologies in a village or a town can affect its image positively (if it is associated with progress or eco-friendliness) or negatively (if it is associated with smell, noise, or low plant aesthetics). This can positively or negatively influence a whole region. The higher the image of a village or a town with regard to bioenergy plants, the better, because people enjoy living in a well-known locality.

(g) Subjective assessment of accident risk

People often associate accident risks or disaster risks with technical plants. This can differ, depending on the technology type, plant type, plant size, etc. The less the assessed risks on a scale of 0 (no risk at all) to 4 (very high risk), the better.

(4) Employment

(a) Additional workplaces

With the usage of local bioenergy for electricity and heat supply, jobs such as a biogas plant manager and also administrative jobs, may be generated. On the other hand, jobs like that of a bioenergy village's chimney sweep are also replaced, because the number of individual heating systems will decrease. The difference between the number of jobs in a village or a region before and after an energy conversion process is another social criterion. The higher the number of additionally created jobs, the better.

(b) Possibility to work part-time

The provision of part-time jobs can contribute to the family life and professional life of men and women being more compatible (OECD 2002, 2005; SEK 2006; Caspar et al. 2005; BMFSJ 2008). Therefore, if a specific biomass concept can provide more part-time jobs than others, it is allocated more points. The crucial value is the number of potential part-time jobs per 1,000 inhabitants.

The social criteria can be viewed in Table 12.3 below.

12.4.4 Technical Criteria

Technical criteria do not follow directly from the three-pillar model of sustainable development as with the other three groups of criteria. However, the authors found it important for the biomass conversion process to report technical criteria separately. In principle, one could also assign the technical criteria to the other three pillars, but this might result in a loss of information. It is important that, within the technical criteria, the ratio of the criteria for the three different pillars – ecology, economy and social aspects – is balanced, or, if not, the weightings of the criteria originating from these three pillars are balanced.

(1) Plant efficiency

Efficiency is generally defined as the ratio between the yielded output and the yielded effort (input). Furthermore, efficiency is an objective of sustainable development in order to minimise the usage of energy and raw materials.

(a) Thermal efficiency factor

The thermal efficiency factor is the ratio of the delivered thermal output to the input energy. The larger this efficiency factor, the better.

(b) Electrical efficiency factor

This is the ratio of the delivered electrical output to the input energy. The larger this efficiency factor, the better.

(c) Heat use in summer

If the heat from the bioenergy plant is used, for example, to warm water (e.g.. for an existing swimming pool), or to dry i.e. wood, corn, clinkers instead of being released into the air, the concept is considered more sustainable. Points are allotted according to a postive answer (one point) and a negative answer (no point).

(d) Modularity

Multiple kettles or biogas plant parts have advantages, because partial workload operation can take place during maintenance, which is positive with regard to emissions and efficiency. The criterion is assigned via points for classes: The higher the number of points, the better.

(2) Biomass transport

Biomass is transported from the fields to the plant and the digested residue is deployed in the fields. Consequently, one needs tractor-drawn trailers or trucks; these lead to noise, energy consumption, emissions and accident risks. The following criteria are relevant here:

(a) Frequency

The less transportation (number of vehicles) needed, the better, as less noise and emissions are produced, fewer accidents occur and the less energy is needed.

(b) Point in time

The more transportation is done during the day (1 point) instead of at night (2 points), the better, due to less noise at bedtime.

(3) Administrative effort (licence duration)

Different approvals are necessary for different kinds and sizes of bioenergy plants; these have associated costs. For example, in Germany, a biogas plant – depending on its size – must comply with a building law and an emissions law (BImSchG). Different approvals have different time-frames. The more complex an energy system, the longer its approval takes. Therefore, the fewer days required for approval, the better.

The technical criteria are shown in Table 12.4 below.

12.5 Bioenergy Alternatives

The research effort's overall aim is to compare the sustainability of different bioenergy concepts regarding a specific geographical location. The socio-geographical framework conditions are defined by the local characteristics of the plant cultivation site (climate, soil type, elevation and air temperature) and the village (population, age distribution and community activities). These characteristics primarily affect energy crop selection, impact the nature and landscape, the yields and the social and economic aspects. The characteristics of such a village influence, inter alia, the demand for energy for electricity and heating. For example, if there is a public swimming pool, or industrial heat customers, the village needs more energy than a "normal" village.

Within these preconditions, two spatial dimensions are considered (Fig. 12.3):

(a) alternative regional bioenergy concepts (regional dimension)
(b) different bioenergy village types as local bioenergy concepts (local dimension).

All the technical bioenergy concepts described are well established and have been available on the market for a long time. The lack of suitable data on new and innovative technologies, i.e. biomass gasification systems has led to their omission from this comparison. We define our base area as farmland; the conversion technologies therefore mostly utilise agricultural products. The woodchip heating plant is only fuelled by local forest products.

For the realisation of bioenergy concepts in a village, the following alternatives are possible:

- the agricultural energy crop cultivation system: conventional farming vs. organic farming vs. crops from contaminated soils[1]

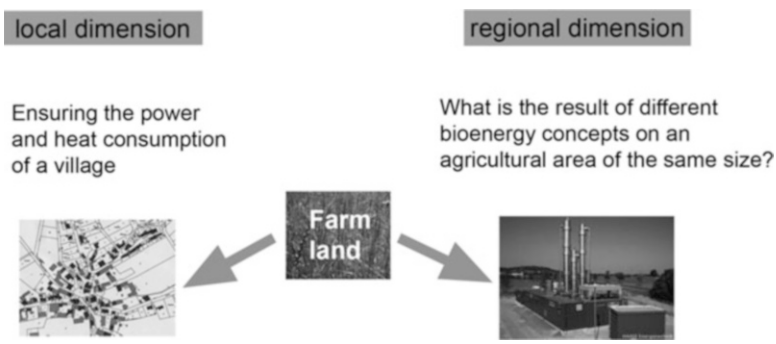

Fig. 12.3 Different spatial dimensions for the comparison of different bioenergy concepts

[1] Cultivation of energy crops on contaminated sites might reduce the competition for agricultural land with food crops (see also Chap. 14).

Table 12.5 Possible combinations for bioenergy villages (local scale)

Cultivation system	conventional	organic	conventional at contaminated site
Biomass fuel	wood	straw	wood from contaminated site
Operation company	people of village	outside investor	farmer group
Participation	yes	no	

- biomass fuel for the woodchip heating plant: wood, straw or wood from contaminated soils
- the operating company: one outside investor, or a corporation with collective investors of whom the majority come from the village, or an investor group comprised of farmers
- the possibility for people to participate in the planning process: yes or no.

The combination of these four aspects (with their particular specifications: 3x3x3x2) leads to 54 theoretically possible alternatives. In an actual bioenergy project, the combinations that are feasible under actual circumstances need to be determined. See Table 12.5 for the various combinations.

For the local dimension, the following presumptions must be met for a comparison of the different approaches to bioenergy villages: The approaches are based on the bioenergy village Jühnde concept. Therefore, the energy conversion techniques will be a biogas plant, a combined heat and power station, a heating plant fuelled by woodchips, a hot water grid, and a boiler fuelled by oil or biodegradable diesel (as a contingency reserve). Furthermore, it is assumed that 70 % of households have a pipe connection to the local hot water grid (see Box 12.1; Ruppert et al. 2008).

On a regional scale, the bioenergy concepts are oriented towards a general bioenergy supply. As a shared reference value for the comparison, the required land area is chosen for a bioenergy village's energy crop cultivation. For example, a bioenergy village needs 300 ha of agricultural land to supply its inhabitants with electricity and heating. These 300 ha will be the land area to be used when comparing the regional biomass concepts. For a large-scale plant, these 300 ha are just a percentage of the whole area that is needed. For a small-scale plant, 300 ha might be more than the plant actually needs. The bioenergy alternatives based on the biogas techniques vary in scale and the type of biogas used. The defined alternatives are listed in Table 12.6.

The challenge is to define appropriate and meaningful alternatives. Data collection and compilation are laborious tasks.

The data relating to the criteria need to be collected and documented with regard to the different alternatives. In the current project, the data will be obtained from the other sub-projects, from databases such as GEMIS and from a literature review.

Table 12.6 Alternative regional bioenergy concepts

Concept	B1: bioenergy village	Large biogas plant	Single biogas plant
Biomass input	Energy crop + wood	Energy crop	Energy crop
Conversion technology	Anaerobic digestion, combustion	Anaerobic digestion, feeding into the gas grid	Anaerobic digestion
Products	Biogas → power, heat	Biogas → power, heat	Biogas → power, heat
Power	716 kW	2.5 MW	225 kW
Arable land area or land use for energy crop cultivation (ha)	~300	~900	~60
Electricity production per year (MWh/a)	4,500	50,000	1,900

Since the focus is on bioenergy villages and their sustainability implications, the investigated bioenergy concepts are deliberately not compared with other renewable energy forms (e.g., wind energy or photovoltaic energy), because the scope would then be too broad and it would be impossible to provide the users with an in-depth differentiated comparison. Nonetheless, Oberschmidt et al. (2010) offer an exemplary comparison of different forms of renewable energy.

12.6 Weighting Process

Once the criteria hierarchy has been established and data on the alternatives have been compiled in the decision table, the weighting process can take place. Weighting factors express the relevance or importance of each attribute. The weighting or valuation of different criteria is a subjective element in the assessment of techniques. It addresses the relative importance of the different criteria of a given decision problem for the decision-maker, or the stakeholder group. The weighting factors thus constitute the preferential information between the criteria (Belton and Stewart 2002). There are several weighting techniques (e.g., direct ratio, SWING (v. Winterfeldt and Edwards 1986), SMART (Edwards 1977; Winterfeldt and Edwards 1986), SMARTER (Barron and Barret 1996; Edwards and Barron 1994), eigen vector method (Saaty 1980), etc.). The discussion of weighting issues leads to the following fundamental questions, especially regarding the valuation of the different criteria of sustainable development:

- Should there be a weighting at all?
- If so, which weighting method should be used?
- Which weights should the different criteria be given?

Scientific research can support decision-makers' quest to better understand the interdependencies in the weighting of environmental criteria. However, this

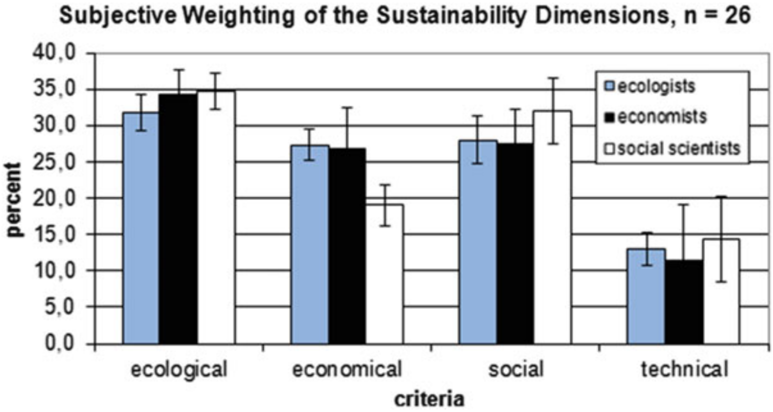

Fig. 12.4 Results of the weighting process of the first criteria level to assess the sustainability of bioenergy paths (*n*: number of people who weighted the importance)

discussion is very controversial, and it should be noted that some authors favour a more technical approach, while others stress the importance of detailed stakeholder involvement due to context sensitivity and the significant influence this has on the overall results.

In our case study, the SWING method (see Winterfeldt and Edwards 1986) was used for the weighting process. The method comprises everybody in a group awarding a number between 0 and 100 to each criterion. The most important criterion is weighted with a high number such as 100, and the others with smaller numbers. The numbers are converted into percentages so that the sum is 100 %, and the percentages of the (in our case between four and seven) experts are averaged (the mean value is calculated).

In this study, the weighting process occurred in three experts groups:

- social experts
- economic experts
- ecological experts.

Each of the expert groups first weighted the relative importance of four sustainability dimensions: the ecology, economy, social aspects and technical aspects. The weighting process occurred in a moderated group. Firstly, each person weighted the criteria individually, thereafter the appraisals were presented to the others and discussed. After this, everyone had an opportunity to change their judgement. The results of the first preliminary weighting process (the decision table is not yet complete) are shown in Fig. 12.4 as a box-and-whisker diagram. The bars show the average of the expressed weighting factors of the four most important criteria in the criterion hierarchy, while the ends of the whiskers represent the minimum and maximum weighting factors allocated by a group of experts.

Figure 12.4 shows that the experts agreed that the ecological criteria should have the highest priority, followed by the social and economic criteria. The technical criteria were seen as the least important. The primacy of the ecological criteria confirms the underlying assumption that the described approach is a strong sustainability concept (see the next section). It should be noted that no engineers or deciders (farmers or designers) participated in this weighting process, only the three expert groups.

Experts may want to change their assigned weighting factors when they see the complete decision table and the applied MCDA algorithm results. Belton and Stewart (2002) state, for example, that the MCDA is an iterative process, and sensitivity analyses will provide further insights into the decision problem, possibly leading to an adjustment of the stated preferences.

12.7 Data Sets for Criteria Specification

12.7.1 Types of Data to Compare Bioenergy Concepts

Complex decision problems call for the involvement of various groups of experts with different scientific or professional backgrounds. Table 12.7 shows the scientific disciplines that contribute to the research project (as described above in the different criteria's sections) and the data type they usually deliver: Natural scientists and engineers mostly produce quantitative or quantifiable data, while social scientists also deliver qualitative results.

Table 12.7 Overview of the participating disciplines in this bioenergy project and the quality of the data used in the MCDA

Disciplines	Data quality	Quantitative or quantifiable data	Qualitative results
Geography	Spatial data (GIS), temporal data (climate data)	X	
Chemistry	Numerical chemical analysis (concentration)	X	
Soil sciences	Numerical chemical analysis (concentration)	X	
Environmental sciences	Spatial data (habitat, biodiversity)	X	X
Psychology	Interviews, questionnaires (motivation, acceptance)	X	X
Economy	Numerical analysis (cash value)	X	
Crop cultivation	Numerical analysis (crop yield, amount of fertiliser)	X	
Agricultural economics	Numerical analysis (contract design), questionnaires (acceptance)	X	X

12.7.2 Data Format

The format of the ecological data is mostly quantitative. Quantitative data are derived from empirical studies as well as from databases, as described in the following sections:

Knowledge about the local availability of biomass for energy is an important aspect in the context of local and regional bioenergy concepts. Therefore, geo-referenced input data on radiation, precipitation, evapotranspiration, temperature and soil properties have to be compared with the cultivation-specific requirements of the different crops on the site to allow the biomass production yield to be modelled (Bauböck 2009; see also Chap. 7 in this book).

The evaluation criteria also consider agricultural activities' impact on the protection of species and biotopes, the landscape, erosion prevention, and other environmental impacts (van Haaren and Bathke 2007; Wiehe et al. 2009). We will also obtain data from other research studies of this type (see Chap. 8 in this book).

An example of a specific bioenergy concept is the use of biomass from contaminated sites for energy. Contaminated sites that may be polluted with hazardous substances (e.g., heavy metals) due to mining activities or flooding by contaminated water offer an interesting option for energy conversion (Deicke et al. 2006; see also Chap. 14 of this book).

The format of the economic and social data is quantitative as well as qualitative. The data are mostly derived from empirical studies, as described in the following section:

Besides economic reasons, farmers' willingness to cultivate energy crops depends on many social or psychological factors such as environmental awareness, risk attitudes, knowledge and involvement (Ruppert et al. 2008; Granoszewski et al. 2009; see also Chap. 9 in this book). Thus, the decision support tool should consider the drivers and barriers revealed through interviews, questionnaires and the subsequent statistical analyses of, for example, the social criteria.

The format of the technical data is mostly quantitative and the data are derived from databases and literature reviews.

12.7.3 Data Consolidation

The consolidation of data from the diverse scientific fields should consider several aspects: The data have different reference values (site-related yields, plant-specific operating costs per year, the share of the population, etc.) and are stored in different formats (shapefile, spreadsheets, text file, etc.). Furthermore, the data quality can vary, as the data from a chemical analysis may have small ranges, while data on the operating level may have a much higher deviation margin. As mentioned above, the comparability of the data should be guaranteed, therefore the units and the reference systems should be comparable; this is the greatest challenge. Furthermore, certain data to be gathered within the collective research project refer to special local conditions (soil, climate, etc.), while data on other criteria have be taken from general databases (e.g., GEMIS). Here, comparability must be proved very thoroughly (see Schmehl et al. 2010).

The development of a consistent life-cycle inventory database faces similar challenges. Hischier and Gilgen (2005) emphasise the relevance of standardised, comprehensive and actual life-cycle inventory databases. In the ECOINVENT project, a clearly defined and comprehensive data exchange format is used, which includes meta-information, modelling, validation and administrative information. Furthermore, there are already approaches to implement geographic information in life-cycle databases, and vice versa. On the one hand, the inventory data can be site-specifically assigned in the geographic information system. On the other hand, the geographic data can be used to identify the correct characterisation and weighting factors for the life-cycle assessment (Wei and Carlson 2002).

12.8 Visualisation

Modern information systems and decision support systems not only store and process data and information, but also display them in a user-friendly manner (Geldermann 2010). Currently, the visual representation of data tables, for example, with bar charts, pie charts, or trend lines, is widely used. In interdisciplinary research topics, the derived research results need to be presented to many lay persons in the various scientific disciplines. For instance, social scientists and natural scientists have to communicate their results to each other. Interested public, such as the village community, or the local administration, also seek advice on building a bioenergy village. Thus, it is essential to present the analysed bioenergy concept's expected advantages and disadvantages for a specific village or region in an easily understandable way.

An open scientific question is the visualisation of specific aspects of the problem to show that some aspects are characterised by far more assessment criteria than others. In decision theory, this is called bias, which is generated by highly asymmetrical criteria hierarchies (Hämäläinen and Alaja 2008).

Profiles will be generated to assess the different bioenergy concepts in order to depict the impacts that sustainable development's three pillars have on direct comparison. Methods from operations research and main component analysis, allow the graphical illustration of a high dimensional solution space (Bertsch et al. 2007; Bertsch et al. 2006; Treitz et al. 2008; Geldermann et al. 2009). Figure 12.5 displays four ways to visualise the results of an MCDA algorithm with regard to the same decision problem (with illustrative data). It should be noted that similar graphical representations are being developed for various MCDA algorithm types, such as multi-attribute utility theory (MAUT), or outranking.

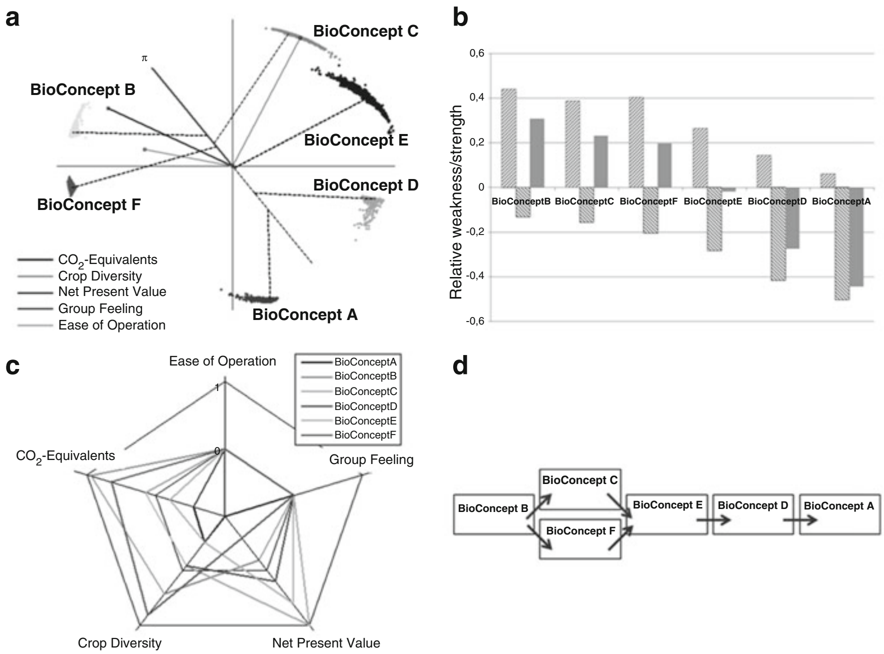

Fig. 12.5 Example of a possible graphical presentation of a PROMETHEE analysis of six biomass concepts (A to F) with regard to five criteria: (**a**) principal components analysis under consideration of uncertainties by means of a Monte Carlo simulation; (**b**) a histogram of the outranking flows; (**c**) a spider diagram; (**d**) a partial pre-order

Geldermann and Schöbel (2011) show that different approaches often have the same mathematical foundation.

Further research is necessary to answer the question on which presentations types most people understand best: Cognitive aspects lead to people perceiving graphically visualised evaluation results in different ways. Exposure to graphical representations is not self-evident or elemental; therefore, their comprehension has to be learned (Cox and Brna 1995; Petre and Green 1993; Weidenmann 1994; Ainsworth 1999). The use of graphics for the visualisation of non-spatial, abstract information – for example, economic data – has only been in common practice in the West since the eighteenth century (Tversky 2000; Roth and Bowen 1999). Consequently, graphical representations can easily be misunderstood, especially by inexperienced or lay persons, and are therefore likely to be interpreted superficially (Weidenmann 1994; Cheng et al. 2001). It is therefore important to edit multi-criteria decision support results graphically, thus allowing perception-psychological knowledge to be considered. This is open to further research by specific psychological studies.

Box 12.4 Representation of Information in the Human Memory

Representation is the illustration of an issue in the mind (Palmer 1978). According to Larkin and Simon (1987), a concept can be differentiated into propositional representations (like language, logical statements, and linearly arranged information) and graphical representations (the use of spatial relations and the availability of information at a glance). On the other hand, individuals' different cognitive styles are also relevant. There are verbalisers and visualisers, i.e. people with different preferences for different types of illustration and, therefore, with a different understanding of them (Cox et al. 1994). Schmuck et al. (1998) examined the intelligibility of various symbols for specific product groups and company groups' assessment according to sustainable development aspects. They showed that various symbols can have very different effects on perception speed and clarity.

12.9 Conclusions

In this chapter, we described the progress of a possible process to choose a special biomass option that is as sustainable as possible. We used an interdisciplinary approach to illustrate the process. The aim of the developed approach is to aggregate different bioenergy concepts' sustainability strengths and weaknesses within a ranking order.

The Multi-Criteria decision analysis (MCDA) helps to structure a decision problem (Department for Communities and Local Government 2009; Geldermann and Rentz 2001; Wilkens and Schmuck 2012). This method seeks to gain insight into the decision problem and to learn more about the investigated alternatives. It increases the transparency of the assessment of the various criteria and alternatives; and therefore reduces the complexity of the decision process. Further, the goal is to distinguish between the subjective and objective preferences specified during the decision process. The alternatives have to be comparable. The itemisation of the indicators (especially the sustainability indicators; see Sect. 12.3) is crucial. In this regard, the development of social criteria within the regional biomass paths is specifically a new research aspect.

We showed that decision support system development is always site-specific for villages and regions. The requirements of local and regional deciders should therefore be considered to support the best choice of a suitable and sustainable concept.

As described, an information system for the assessment of different bioenergy concepts with regard to sustainable development has to manage data on ecological, economic, social and technical aspects. On the synthesis side, there are data on geo-referenced environmental information, acceptance surveys, bioenergy plants' technical characteristics, the documentation of interviews and questionnaires, chemical analysis results, etc. The weighting process is also a differentiated step that should be undertaken by experts who are deeply involved in sustainable development. The challenge is therefore not only the vast amount of data in very non-homogeneous formats, but especially the mastering of the logical coherence of the data from different sources and scenarios. In addition, a vast base of experience with and knowledge of sustainable development is essential, which will inevitably lead to an interdisciplinary discussion.

After the interdisciplinary effort to establish a criteria system and to calculate the criteria values, or the relative strengths and weaknesses of individual biomass alternatives, it is crucial that the results should be understood by as many people as possible, because people need to accept one of the alternatives. Again, this participatory aspect is part of a sustainable biomass concept. Wilkens and Schmuck (2012) describe this process as follows: The MCDA process offers a platform for the exchange of arguments and different perspectives, provides data that can answer residents' questions, and combines scientific data with the actors' perspectives, thus making well-balanced decision-making possible. This requires the professional preparation of the MCDA process in the form of well-understood visual presentations. Only then will the theoretic scientific effort lead to the successful application – also by lay people – and support of a more sustainable life on earth.

To date, the spatial and temporal scaling problematic is unsolved. Specifically, in the field of interdisciplinary research, in which economists, natural scientists and social scientists work and collect data on different scales, further research is needed to extrapolate and model the data from one scale to another in the different research fields and to combine them properly. Ensuring the comparability of different data sources is another great challenge.

The results of the process depicted here can contribute to sustainable development. The scientific findings we describe can help preserve biodiversity, reduce global warming, rekindle village life, strengthen the democratic will, consolidate regions' economic potential and strengthen rural development.

References

Ahl, C., Eigner-Thiel, S., Girschner, W., Karpenstein-Machan, M., Roland, F., Ruppert, H., Ruwisch, V., Sauer, B., Scheffer, K., & Schmuck, P. (2007). *Bioenergiedörfer – Dörfer mit Zukunft,* Information brochure. Göttingen: Interdisciplinary Centre for Sustainable Development.

Ainsworth, S. (1999). *Designing effective multi-representational learning environments* (Report no. 58). Nottingham: University of Nottingham, ESRC Centre for research in Development, Instruction and Teaching.

Bandura, A. (1992). Exercise of personal agency through the self-efficacy mechanism. In R. Schwarzer (Ed.), *Self-efficacy: Thought control of action* (pp. 3–38). Washington, DC: Hemisphere.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Barron, F. H., & Barret, B. E. (1996). Decision quality used ranked attribute weights. *Management Science, 42*, 1515–1523.

Bauböck, R. (2009). Bioenergie im Landkreis Göttingen – GIS-gestützte Biomassenpotenzialabschätzung anhand ausgewählter Energiepflanzen, Triticale und Mais (Band 18). In

M. Kappas (Ed.), *Erdsicht – Einblicke in geographische und geoinformationstechnische Arbeitsweisen*. Stuttgart: Ibidim-Verlag.

Belton, V., & Stewart, T. J. (2002). *Multiple criteria decision analysis: An integrated approach*. Dordrecht: Kluwer Academic Publishers.

Bertsch, V., Geldermann, J., Rentz, O., & Raskob, W. (2006). Multi-criteria decision support and stakeholder involvement in emergency management. *International Journal of Emergency Management, 3*(2/3), 114–130.

Bertsch, V., Treitz, M., Geldermann, J., & Rentz, O. (2007). Sensitivity analyses in multi-attribute decision support for off-site nuclear emergency and recovery management. *International Journal of Energy Sector Management, 1*(4), 342–365.

BioSt-NachV. (2009). Verordnung über Anforderungen an eine nachhaltige Herstellung von flüsssiger Biomasse zur Stromerzeugung. *Bundesgesetzblatt Jahrgang 2009, Teil 1*, Nr. 46. Bonn.

BMFSJ. (2008). *Familienfreundlichkeit als Erfolgsfaktor für die Rekrutierung und Bindung von Fachkräften. Ergebnisse einer repräsentativen Umfrage unter Arbeitgebern und Beschäftigten*. Retrieved August 23, 2010, from: http://www.bmfsfj.de/bmfsfj/generator/BMFSFJ/Service/Publikationen/publikationsliste,did=112440.html

BMU (Federal Ministry for the Environment, Nature conservation and Nuclear Safety). (1992). *Umweltpolitik*. Agenda 21. Konferenz der Vereinten Nationen für Umwelt und Entwicklung im Juni 1992 in Rio de Janeiro. Berlin, Germany.

BMU (Federal Ministry for the Environment, Nature conservation and Nuclear Safety). (2009). *German cabinet has approved national biomass action plan*. Press release no. 122/09. Berlin, Germany.

Bouwman, A. F., van Vuuren, D. P., Derwent, R. G., & Posch, M. (2002). A global analysis of acidification and eutrophication of terrestrial ecosystems. *Water, Air, and Soil Pollution, 141*, 349–382.

Breitschuh, G., Breitschuh, T., & Eckert, H. (2008). Einfluss einer erhöhten Biomasseproduktion auf die Nachhaltigkeitsparameter landwirtschaftlicher Betriebe. In Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL) (Ed.), *Ökologische und ökonomische Bewertung nachwachsender Energieträger* (pp. 104–116). Darmstadt: KTBL.

Buchholz, T., Rametsteiner, E., Volk, T. A., & Luzardis, V. A. (2009). Multi-criteria analysis for bioenergy systems assessments. *Energy Policy, 37*(2), 484–495.

Caspar, S., Kirchmann, A., Seibold, B., & Stieler, S. (2005). *Kinder, Konflikt, Karriereknick. Notwendigkeiten und Ansatzpunkte für eine bessere Vereinbarkeit von Familie und Beruf*. Tübingen: IAW Forschungsberichte, 65. IMU-Infodienst (2).

Cheng, P. C.-H., Lowe, R. K., & Scaife, M. (2001). Cognitive science approaches to understanding diagrammatic representations. *Artificial Intelligence Review, 15*, 79–94.

Cordell, D., Drangert, J.-O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change, 19*, 292–305.

Cox, R., & Brna, P. (1995). Supporting the use of external representations in problem solving: The need for flexible learning environments. *Journal of Artificial Intelligence in Education, 6*(2/3), 239–302.

Cox, R., Stenning, K., & Oberlander, J. (1994). *Graphical effects in learning logic: reasoning, representation and individual differences*. In Proceedings of the 16th annual conference of the Cognitive Science Society. Hillsdale: Lawrence Erlbaum Associates.

Daly, H. (1999). *Wirtschaft jenseits von Wachstum: Die Volkswirtschaftslehre nachhaltiger Entwicklung*. Salzburg: Pustet.

DEIAGRA (Dipartimento di Economica ed Ingeneria Agrarie). (2008). *The competition between food crops and non food crops for energy*. European Parliament, Brussels.

Deicke, M., Ruppert, H., & Schneider, J. (2006). Mining and smelting in the Harz mountains (Germany) – A neverending environmental story. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, 45*, 237–256.

Delzeit, R., Gömann, H., Holm-Müller, K., Kreins, P., Kretschmer, B., Münch, J., & Peterson, S. (2010). *Analysing bioenergy and landuse competition in a coupled modelling system: The* *role of bioenergy in renewable energy policy in Germany*. Kiel: Kiel Institute for the World Economy.

Department for Communities and Local Government. (2009). *Multi-criteria analysis: A manual*. London: Department for Communities and Local Government.

Dörner, D. (2003). *Die Logik des Misslingens – Strategisches Denken in komplexen Situationen*. Hamburg: Rowohlt.

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Arvizu, D., Bruckner, T., Christensen, J., Devernay, J. M., Faaij, A., Fischedick, M., Goldstein, B., Hansen, G., Huckerby, J., Jäger-Waldau, A., Kadner, S., Kammen, D., Krey, V., Kumar, A., Lewis, A., Lucon, O., Matschoss, P., Maurice, L., Mitchell, C., Moomaw, W., Moreira, J., Nadai, A., Nilsson, L. J., Nyboer, J., Rahman, A., Sathaye, J., Sawin, J., Schaeffer, R., & Schei, T. (2011). Summary for policy makers. In S. Schlömer, R. Sims, A. Verbruggen, C. von Stechow, K. Urama, R. Wiser, F. Yamba, T. Zwickel, O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, & C. V. Stechow (Eds.), *IPCC special report on renewable energy sources and climate change mitigation*. Cambridge: Cambridge University Press.

Edwards, W. (1977). How to use multiattribute utility measurement for social decision making. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-7*, 326–340.

Edwards, W., & Barron, F. H. (1994). SMARTS and SMARTER: Improved simple methods for multiattribute utility measurement. *Organizational Behaviour and Human Decision Processes, 60*, 306–325.

Eigner-Thiel, S. (2005). *Kollektives Engagement für die Nutzung erneuerbarer Energieträger – Motive, Mobilisierung und Auswirkungen am Beispiel des Aktionsforschungsprojektes "Das Bioenergiedorf"*. Hamburg: Kovac.

Eigner-Thiel, S. (2010). Psychologie. In Projektgruppe Bioenergiedörfer (Hrsg.), *Das Bioenergiedorf – Voraussetzungen und Folgen einer eigenständigen Wärme- und Stromversorgung durch Biomasse für Landwirtschaft, Ökologie und Lebenskultur im ländlichen Raum*. Göttingen: Institut für Bioenergiedörfer Göttingen e.V., Schriftenreihe "Fortschritt neu denken", Heft 1, 106–149.

Eigner-Thiel, S., & Geldermann, J. (2009). Entscheidungsunterstützung bei der Planung eines Bioenergiedorfes. In J. Geldermann & L. Lauven (Eds.), *Einsatz von OR-Verfahren zur Entscheidungsunterstützung*. Aachen: Shaker.

Eigner-Thiel, S., & Schmuck, P. (2010). Gemeinschaftliches Engagement für das Bioenergiedorf Jühnde: Ergebnisse einer Längsschnittstudie zu psychologischen Auswirkungen auf die Dorfbevölkerung. *Umweltpsychologie, 14*(2), 27, 98–120.

European Parliament. (2009). *Directive 2009 / 28 EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC*. Official Journal of the European Union.

Ferge, T., Maghun, J., Hafner, K., Mühlberger, F., Davidovic, M., Warnecke, R., & Zimmermann, R. (2005). On-line analysis of gas-phase composition in the combustion chamber and particle emission characteristics during combustion of wood and waste in a small batch reactor. *Environmental Science and Technology, 39*, 1393–1402.

Figueira, J., Greco, S., & Ehrgott, M. (2005). *Multiple criteria decision analysis – State of the art. Surveys*. New York: Springer.

Fleury, A. (2005). *Eine Nachhaltigkeitsstrategie für den Energieversorgungssektor – dargestellt am Beispiel der Stromversorgung in Frankreich*. Karlsruhe: University of Karlsruhe (TH), French-German Institute for Environmental Research.

Fritsche, U. R., Jenseit, W., & Hochfeld, C. (1999). *Methodikfragen bei der Berechnung des Kumulierten Energieaufwands (KEA)*. Darmstadt: Öko-Institut e.V.

Fritsche, U. R., Hennenberg, K., Hermann, A., Hünecke, K., Schulze, F., Wiegmann, K., et al. (2009). *Sustainable bioenergy: Current status and outlook*. Darmstadt/Heidelberg: Öko-Institut e.V./Institute for Energy and Environmental Research.

Gallego Schmid, A. (2009). *Calculation of LCA characterization factors for terrestrial eutrophication at regional scale*. Presentation at the IX Conference “toward the global life cycle economy” 28th September–2nd October 2009. Boston: American Center for Life Cycle Assessment.

Gamba, L. (2008). *Erste Modellentwicklung zur nachhaltigen Nutzung von Biomasse*. Doctoral dissertation, Technical University Berlin, Germany.

Geldermann, J. (2010). Explanation systems. In D. Rios Insua & S. French (Eds.), *e-Democracy: A group decision and negotiation perspective* (pp. 241–259). Berlin: Springer.

Geldermann, J., & Rentz, O. (2001). Integrated technique assessment with imprecise information as a support for the identification of best available techniques (BAT). *OR Spectrum, 23*, 137–157.

Geldermann, J., & Rentz, O. (2004). The reference installation approach for the techno-economic assessment of emission abatement options and the determination of BAT according to the IPPC-directive. *Journal of Cleaner Production, 12*, 389–402.

Geldermann, J., Bertsch, V., Treitz, M., French, S., Papamichail, K. N., & Hämäläinen, R. P. (2009). Multi-criteria decision support and evaluation of strategies for nuclear remediation management. *OMEGA – The International Journal of Management Science, 37*(1), 238–251.

Geldermann, J., & Schöbel, A. (2011). On the similarities of some MCDA methods. *Journal of Multi-Criteria Decision Analysis, 18*(3–4), 219–230.

Geldermann, J., Jahn, C., Spengler, T., & Rentz, O. (1999). Proposal for an integrated approach for the assessment of cross-media aspects relevant for the determination of “best available techniques” BAT in the European Union. *International Journal of Life Cycle Assessment, 4*(2), 94–106.

Girschner, W., & Girschner-Woldt, I. (2007). Diaphane Planung als Modell nachhaltigkeitsorientierter Planungspraxis. In E. J. Krauß, M. Müller, & R. Münchmeier (Eds.), *Soziale Arbeit zwischen Ökonomisierung und Selbstbestimmung*. Kassel: University Press.

Granoszewski., K., Reise, C., Spiller, A., & Mußhoff, O. (2009). *Entscheidungsverhalten landwirtschaftlicher Betriebsleiter bei Bioenergie-Investitionen* (Discussion Paper No. 0911). Göttingen: University of Göttingen, Department of Agricultural Economics and Rural Development.

Gromke, U., & Detzel, A. (2006). *Ecological comparison of office papers in view of fibrous raw material*. Heidelberg: Institute for Energy and Environmental Research.

Guski, R. (2000). *Wahrnehmung – eine Einführung in die Psychologie der menschlichen Informationsaufnahme*. Stuttgart: Kohlhammer.

Hämäläinen, R. P., & Alaja, S. (2008). The threat of weighting biases in environmental decision analysis. *Ecological Economics, 68*(1/2), 556–569.

Heiland, S., Tischer, M., Döring, T., Pahl, T., & Jessel, B. (2003). *Indikatoren zur Zielkonkretisierung und Erfolgskontrolle im Rahmen der Lokalen Agenda 21*. Berlin: Umweltbundesamt.

Heijungs, R., Guinée, J. B., Huppes, G., Lankreijer, R. M., Udo de Haes, H. A., & Wegener Sleeswijk, A. (1992). *Environmental life cycle assessment of products – Backgrounds*. Leiden: Centrum voor Milieukunde.

Helsinki Conference. (1993). *Second ministerial conference on the protection of forests in Europe*. 16–17 June 1993, Helsinki/Finland.

Hewitt, C. N., & Jackson, A. V. (Eds.). (2003). *Handbook of atmospheric science*. Malden: Blackwell.

Hischier, R., & Gilgen, P. W. (2005). Life cycle assessment databases as part of sustainable development strategies: The example of ecoinvent. In L. M. Hilty, E. K. Seifert, & R. Treibert (Eds.), *Information systems for sustainable development* (pp. 15–24). Hershey: Idea Group Publishing.

Hoffmann, D. (2007). *Regionale Wertschöpfung durch optimierte Nutzung endogener Biomassepotenziale*. Doctoral dissertation, Saarland University, Germany.

Hofstetter, P. (1998). *Perspectives in life cycle impact assessment; a structured approach to combine models of the technosphere, ecosphere and valuesphere*. Dordrecht: Kluwer Academic Publishers.

Hughes, L. (2003). Climate change and Australia: Trends, projections and impacts. *Austral Ecology, 28*(4), 423–443.

Huijbregts, M. A. J., Rombouts, L. J. A., Hellweg, S., Frischknecht, R., Hendriks, J., van de Meent, D., Ragas, A. M. J., Reijnders, L., & Struijs, J. (2006). Is cumulative fossil energy demand a useful indicator for the environmental performance of products? *Environmental Science and Technology, 40*(3), 641–648.

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making, methods and applications – A state-of-the-art survey*. Heidelberg: Springer.

IEA (International Energy Agency). (2004). *Biofuels for transport: An international perspective*. Paris: IEA.

IPCC. (2007). Fourth assessment report: Climate change 2007. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), *The physical science basis*. New York: Cambridge University Press.

Ipsen, D. (1993). Regionale Identität. *Überlegungen zum politischen Charakter einer psychosozialen Raumkategorie. Raumforschung und Raumordnung, 51*, 9–18.

Jessel, B. (2008). *Biodiversity and bioenergy*. Presentation at the 9th meeting of the Conference of the Parties (COP 9), 19.-30.05. 2008. Bonn, Germany.

Kempener, R., Beck, J., & Petrie, J. (2009). Design and analysis of bioenergy networks. *Journal of Industrial Ecology, 13*, 284–305.

Kimming, M., Sundberg, C., Nordberg, A., Baky, A., Bernesson, S., Norén, O., & Hansson, P. A. (2011). Biomass from agriculture in small-scale combined heat and power plants – A comparative life cycle assessment. *Biomass and Bioenergy, 35*(4), 1572–1581.

Kort, J., Collins, M., & Ditsch, D. (1998). A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy, 14*(4), 351–359.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*, 65–99.

Leitl, T. (2007). *Biomasse, Bestandteil der RWE-Strategie im Bereich erneuerbare Energien*. Presentation at the 2nd bioEnergy conference Carinthia, 06.11.2007. Velden, Austria.

Lenz, V. A. (2010). *Feinstaubminderung im Betrieb von Scheitholzkaminöfen unter Berücksichtigung der toxikologischen Relevanz*. DBFZ Report Nr. 3. Leipzig.

Lobb, D. A., Gary Kachanoski, R., & Miller, M. H. (1999). Tillage translocation and tillage erosion in the complex upland landscapes of southwestern Ontario, Canada. *Soil and Tillage Research, 51*(3–4), 189–209.

Malczewski, J. (1999). *GIS and multicriteria analysis*. New York: Wiley.

Miller, G. A. (1956). The magic number seven plus or minus two: Some limits on our capacity for communicating information. *Psychological Review, 63*, 81–97.

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being. Current state and trends*. Washington, DC: Island Press.

Monier V., & Labouze E. (2001). *Critical review of existing studies and life cycle analysis on the regeneration and incineration of waste oils*. In European Commission, DG Environment.

Munda, G. (1995). *Multicriteria evaluation in a fuzzy environment: Theory and applications in ecological economics*. Heidelberg: Physika-Verlag.

Mustajoki, J., Hämäläinen, R. P., & Martunen, M. (2003). Participatory multicriteria decision analysis with Web-HIPRE: A case of lake regulation policy. *Environmental Modelling & Software. Vol., 19*(6), 537–547.

Nixon, S. C., Lack, T. J., Hunt, D. T. E., Lallana, C., & Boschet, A. F. (2000). *Sustainable use of Europe's water?* Copenhagen: European Environment Agency.

NUTS (2007). Verordnung (EG) Nr. 105/2007 der Kommission vom 1. Februar 2007 zur Änderung der Anhänge der Verordnung (EG) Nr. 1059/2003 des Europäischen Parlaments und des Rates über die Schaffung einer gemeinsamen Klassifikation der Gebietseinheiten für die Statistik.

Oberschmidt, J., Ludwig, J., & Geldermann, J. (2009). Ein modifizierter PROMETHEE-Ansatz zur Lebenszyklus-orientierten Bewertung der Strom- und Wärmeversorgung. In J. Geldermann & L. Lauven (Eds.), *Einsatz von OR-Verfahren zur Entscheidungsunterstützung*. Aachen: Shaker.

Oberschmidt, J., Geldermann, J., Ludwig, J., & Schmehl, M. (2010). Modified PROMETHEE approach to assessing energy technologies. Special issue: Uses of frontier efficiency methodologies and multi-criteria decision making for performance measurement in the energy sector. *International Journal of Energy Sector Management, 4*(2), 183–212.

OECD. (2002). *Family-friendly policy can generate a range of benefits to society*. Retrieved August 23, 2010, from http://www.oecd.org/document/10/0,3343,en_21571361_44315115_1837194_1_1_1_1,00.html

OECD. (2005). *Trends and determinants of fertility rates. The role of policies, social, employment and migration* (Working Paper No 27). Paris: OECD.

Ott, K. (2003). The case for strong sustainability. In K. Ott & P. Thapa (Eds.), *Greifswald's environmental ethics*. Greifswald: Steinbecker Verlag Ulrich Rose.

Page, B., & Rautenstrauch, C. (2001). Environmental informatics-methods, tools and applications in environmental information processing. In C. Rautenstrauch & S. Patig (Eds.), *Environmental information systems in industry and public administration* (pp. 2–11). Hershey: Idea Group Publishing.

Palmer, S. E. (1978). Fundamental aspects of cognitive representation. In E. Rosch & B. B. LLoyd (Eds.), *Cognition and categorization* (pp. 259–303). Hillsdale: Erlbaum.

Petre, M., & Green, T. R. G. (1993). Learning to read graphics: Some evidence that 'seeing' an informational display is an acquired skill. *Journal of Visual Languages and Computing, 4*, 55–70.

Pimentel, D. (2006). Soil erosion: A food and environmental threat. *Environment, Development and Sustainability, 8*, 119–137.

Projektgruppe Bioenergiedörfer. (2010). *Das Bioenergiedorf – Voraussetzungen und Folgen einer eigenständigen Wärme- und Stromversorgung durch Biomasse für Landwirtschaft, Ökologie und Lebenskultur im ländlichen Raum*. Göttingen: Institut für Bioenergiedörfer Göttingen e.V., Schriftenreihe "Fortschritt neu denken", Heft 1.

Rautenstrauch, C. (1999). *Betriebliche Umweltinformationssysteme, Grundlagen, Konzepte und Systeme*. Berlin/Heidelberg: Springer.

Reul, F. (2002). *Entwicklung einer Nachhaltigkeitsstrategie für den Stadtverkehr – das Beispiel Berlin*. Doctoral dissertation, Humboldt-University Berlin, Germany. Retrieved July 13, 2009, from http://edoc.hu-berlin.de/dissertationen/reul-frithjof-2002-12-17

Rodrígues, L., Reuter, H. I., & Hengl, T. (2008). A framework to estimate the distribution of heavy metals in European soils. In G. Tóth, L. Montanarella, & E. Rusco (Eds.), *Threats to soil quality in Europe* (pp. 79–86). Ispra: Joint Research Centre, European Commission.

Roedl, A. (2010). Production and energetic utilization of wood from short rotation coppice – A life cycle assessment. *International Journal of Life Cycle Assessment, 15*(6), 567–578.

Rösch, C., Skarka, J., Raab, K., & Stelzer, V. (2009). Energy production from grassland – Assessing the sustainability of different process chains under German conditions. *Biomass and Bioenergy, 33*(4), 689–700.

Roth, W.-M., & Bowen, G. M. (1999). Of cannibals, missionaries, and converts: Graphing competencies from grade 8 to professional science inside (classrooms) and outside (field/laboratory). *Science, Technology, and Human Values, 24*(2), 179–212.

Ruppert, H., Eigner-Thiel, S., Girschner, W., Karpenstein-Machan, M., Roland, F., Ruwisch, V., Sauer, B., & Schmuck, P. (2008). *"Wege zum Bioenergiedorf" – Leitfaden für eine eigenständige Wärme- und Stromversorgung auf Basis von Biomasse im ländlichen Raum*. Gülzow: Fachagentur Nachwachsende Rohstoffe.

Rusco, E., Montanarella, L., & Bosco, C. (2008). Soil erosion: A main threats to the soil in Europe. In G. Tóth, L. Montanarella, & E. Rusco (Eds.), *Threats to soil quality in Europe European Commission* (pp. 37–45). Ispra: Joint Research Centre.

Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw Hill.

Schmehl, M., Eigner-Thiel, S., Hesse, M., Ibendorf, J., & Geldermann, J. (2010). Development of an information system for the assessment of different bioenergy concepts regarding sustainable development. In M. G. Teuteberg (Ed.), *Corporate environmental management information systems: Advancements and trends* (pp. 318–336). Hershey: IGI Global.

Schmehl, M., Hesse, M., & Geldermann, J. (2012). *Ökobilanzielle Bewertung von Biogasanlagen unter Berücksichtigung der niedersächsischen Verhältnisse*. Research Paper der Georg-August-Universität Göttingen, Wirtschaftswissenschaftliche Fakultät, Schwerpunkt Unternehmensführung, Professur für Produktion und Logistik, Nr.11, Göttingen.

Schmitz, S. (1995). *Ökobilanz für Getränkeverpackungen*. Berlin: Umweltbundesamt.

Schmitz, S., & Paulini, I. (1999). *Valuation as an element of life cycle assessment – German Federal Environmental Agency method for impact indicator standardization, impact category grouping (ranking), and interpretation in accordance with ISO 14042 and 14043*. In Federal Environmental Agency, Berlin.

Schmuck, P., Eigner, S., Kaufhold, A., & Krapoth, S. (1998). *Psychologische Aspekte von Unternehmensbewertung*. Schriftenreihe des Koordinations- und Studienzentrums Frieden und Umwelt, Heft 13. Göttingen, Germany.

SCOPE (Scientific Committee on Problems of the Environment). (1995). *Environmental indicators: systematic approach to measuring and reporting on the environment in the context of sustainable development*. Discussion paper presented at the workshop "International Consultation of Sustainable Development Indicators", Ghent. Bruxelles, Belgium: Bureau du Plan.

SEK. (2006). *Mitteilung der Kommission an den Rat, das Europäische Parlament, den Europäischen Wirtschafts- und Sozialausschuss und den Ausschuss der Regionen – Ein Fahrplan für die Gleichstellung von Frauen und Männern 2006–2010*. Retrieved August 23, 2010, from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0092:FIN:DE:HTML

SETAC. (1996). Towards a methodology for life cycle impact assessment. In *Society of environmental toxicology and chemistry*, Brussels.

Thuiller, W., Lavergne, S., Roquet, C., Boulangeat, I., Lafourcade, B., & Araujo, M. (2011). Consequences of climate change on the tree of life in Europe. *Nature, 470*(7335), 531–534.

Treitz, M., Bertsch, V., Schollenberger, H., Geldermann, J., & Rentz, O. (2008). *Multi-criteria decision support for process design*. International Transactions in Operational Research (accepted), Vol. Special, Issue of the IFORS conference in Hawaii 2005, 10–15 July Honolulu, Hawaii.

Tversky, B. (2000). Some ways maps and diagrams communicate. In C. Freksa, W. Brauer, C. Habel, & K. F. Wender (Eds.), *Spatial cognition II*. Berlin: Springer.

Udo de Haes, H. A. (1996). *Towards a methodology for life cycle impact assessment*. Brussels: SETAC-Europe.

UNCED. (1992). *Earth Summit, United Nations conference on environment and development,* Rio de Janeiro, 3–14 June 1992

United Nations. (1987). General Assembly Resolution, 42/187.

Van Haaren, C., & Bathke, M. (2007). Integrated Planning and remuneration of agri-environmental goods and services for the management of sustainable landscapes – Results of a case study in the Fuhrberg region of Germany. *Journal of Environmental Management, 89*, 209–221.

Van Loo, S., & Koppejan, J. (Eds.). (2008). *Handbook of biomass combustion and co-firing*. London: Earthscan.

VDI (1997). *Cumulative energy demand – Terms, definitions, methods of calculation*. In Verein Deutscher Ingenieure (VDI) (Ed.). Düsseldorf: Beuth Verlag.

Vester, F. (2003). *Die Kunst, vernetzt zu denken Ideen und Werkzeug für einen Umgang mit Komplexität Der neue Bericht an den Club of Rome*. München: dtv.
Vis, M. W., Vos, J.,& van den Berg, D. (2008). *Sustainability criteria & certification systems for biomass production*. Final report no. 1386 for the European Commission. Brussels
von Winterfeldt, D., & Edwards, W. (1986). *Decision analysis and behavioral research*. Cambridge: Cambridge University Press.
WBGU. (2008). *Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen. Zukunftsfähige Bioenergie und nachhaltige Landnutzung*. Berlin: Springer.
Weber-Blaschke, G., Frieß, H., Peichl, L., & Faulstich, M. (2002). Aktuelle Entwicklungen bei Umweltindikatorensystemen. *Zeitschrift für Umweltwissenschaften und Schadstoffforschung, 14*(3), 187–193.
Wei, B., & Carlson, R. (2002). *Practical Pre-Study of GIS application with LCA database SPINE*. Presentation at the fifth international conference on Ecobalance, November 6–8, 2002. Tsukuba, Japan.
Weidenmann, B. (Ed.). (1994). *Wissenserwerb mit Bildern*. Bern: Huber.
Werheit, M. (1996). *Indikatoren für eine nachhaltige Entwicklung*. Information letter No. 29 of the Independent Institute for Environmental Concerns (UfU), Berlin, Germany.
Wiehe, J., Ruschkowski, E., Rode, M., Kanning, H., & Haaren, C. v. (2009). Auswirkungen des Energiepflanzenanbaus auf die Landschaft am Beispiel des Maisanbaus für die Biogasproduktion in Niedersachsen. *Naturschutz und Landschaftsplanung, 41*(4), 107–113.
Wilkens, I. (nee Braune), & Schmuck. P (2012). Transdisciplinary evaluation of energy scenarios for a German village using multi-criteria decision analysis. *Sustainability, 4*(4), 604–629.
World Health Organization. (2006). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. Geneva: World Health Organization.
Wuppertal-Institut für Klima, Umwelt, Energie. (1997). *Zukunftsfähiges Deutschland – ein Beitrag zu einer global nachhaltigen Entwicklung*. Basel: Birkhäuser.
Wüste, A., & Schmuck, P. (2012). Bioenergy villages and regions in Germany: An interview study with initiators of communal bioenergy projects on the success factors for restructuring the energy supply of the community. *Sustainability, 4*(2), 244–256. doi:10.3390/su4020244. Retrieved December 3, 2012, from http://www.mdpi.com/2071-1050/4/2/244/
Yue, C. Y., & Li, H. (1998). Multi-attribute evaluation for environment, resource and sustainable development. *Monitoring and Assessment, 12*, 28–30.