Modelling and Tools Supporting the Transition to a Bioeconomy

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Elisabeth Angenendt, Witold-Roger Poganietz, Ulrike Bos, Susanne Wagner, and Jens Schippl

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E. Angenendt (✉)
Institute of Farm Management; Farm Management, University of Hohenheim, Stuttgart, Germany
e-mail: Elisabeth.Angenendt@uni-hohenheim.de

W.-R. Poganietz
Research Area Energy – Resources, Technologies, Systems, Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology, Karlsruhe, Germany
e-mail: poganietz@kit.edu

U. Bos
Department Life Cycle Engineering (GaBi), Institute for Acoustics and Building Physics, University of Stuttgart, Stuttgart, Germany

Thinkstep AG, Leinfelden-Echterdingen, Germany
e-mail: ulrike.bos@thinkstep.com

S. Wagner
Institute of Agricultural Policy and Markets; Agricultural and Food Policy, University of Hohenheim, Stuttgart, Germany

Center for Environmental Systems Research (CESR), University Kassel, Kassel, Germany
e-mail: susanne.wagner@uni-kassel.de

J. Schippl
Research Area Innovation Processes and Impacts of Technology, Institute for Technology Assessment and Systems Analysis (ITAS), Karlsruhe Institute of Technology, Karlsruhe, Germany
e-mail: jens.schippl@kit.edu

Abstract

The strategy of using biogenic resources in a bioeconomy could be seen as one answer to the geopolitical challenges the world is facing in the twenty-first century. One of those challenges is the closing of the prosperity gap between rich and poor countries. However, considering the current global population growth and anthropogenically induced climate change, it is expected that efforts to achieve this goal will be accompanied by an increasing demand for food, feed, products, and energy, which cannot be satisfied by the expected supply of non-biogenic raw materials and resources.

Transforming an economy is extremely complex: domestic and international obligations, traditional practices, and divergent interests and wishes need to be taken into consideration. This requires the development of an appropriate strategy and adequate instruments and tools to support it.

This chapter discusses a range of possible knowledge-based instruments and tools that take a systemic view of the challenges in such transformation processes.

Keywords

Scenarios • Scenario building • Economic models • Ecological and biophysical models • Life cycle assessment • Integrated assessment models

Learning Objectives

After studying this chapter, you should:

- Understand how transformation theory can support transition processes.
- Have an overview of main instruments and tools to quantify and assess transition developments.
- Be acquainted with the main challenges, strategies and drivers to facilitate the transition to a bioeconomy.

9.1 Introduction

One core geopolitical challenge in the twenty-first century is closing the prosperity gap between rich and poorer countries. However, this needs to be achieved in a world with a growing population, unevenly distributed growth and anthropogenically induced climate change with significant regional variation in its impact.

Since rich countries are unlikely to renounce their wealth, closing the prosperity gap will be accompanied by an increasing demand for food, feed, products, and energy. It is expected, however, that in the longer run, increasing demand will not be satisfied by the available supply of metals, minerals, and fossil fuels. Recycling strategies can reduce the pressure on primary resources, but even with technological progress, excess demand for non-renewable materials will not be sufficiently lowered.

Climate change and increasing pressure on the natural environment demand a change in strategy. For this reason, the European Commission, among others, proposes a radical change in "its approach to production, consumption, processing, storage, recycling and disposal of biological resources" (European Commission 2012). This bioeconomic strategy needs to:

- Ensure food security.
- Manage natural resources.

- Reduce dependence on non-renewable resources.
- Mitigate and adapt climate change.
- Create jobs and maintain competitiveness especially—but not exclusively—in rural areas.

Whereas the challenges to be addressed are widely known and accepted, the question of how these goals can be achieved, i.e. how an economy can be transformed into a bioeconomy, is still at the centre of scientific, political, and societal debate.

Historical evidence from recent decades demonstrates society's essential role in any successful transformation of systems. Norms, values, and thus behavioural patterns, along with the degree of acceptance and the willingness to support changes, are as important as technological and economic factors (Verbong and Loorbach 2012). These norms and values shape the preferences of what a future bioeconomy should look like. Any thinking about the future is accompanied by uncertainties and relevant but as yet unknown processes within and outside the control of stakeholders.

The development of potentially successful strategies for dealing with uncertainties on the way to a bioeconomy requires instruments and tools to depict possible transition paths. This chapter provides the reader with a number of instruments and tools, without claiming to be comprehensive.

To identify future possibilities, scenarios have increasingly been used in the past decades. They address complexities and uncertainties by explicitly acknowledging that different futures are possible and that reliable, long-term predictions in the field of sociotechnical transition are not possible (Grunwald 2011). Scenarios aim to explore and develop potential or desirable future states and development pathways. One established approach is to combine scenarios with models (Poganietz et al. 2000). Models can reveal interdependencies between resources, production, consumption, markets and sectors, and the environment.

9.2   Scenarios: Revealing the Trails into the Future

This section presents the scenario approach. First, the necessity of scenarios is explained (Sect. 9.2.1), followed by a discussion of their function in science and the public (Sect. 9.2.2). Because scenarios are used in different contexts, a typology of scenario approaches is shown in Sect. 9.2.3. Section 9.2.4 aims to assist the development of scenarios. The section ends with some concluding remarks (Sect. 9.2.5).

> **Scenarios**
> Scenarios describe complex pictures of the future that are seen as plausible. The described future can be modelled according to current knowledge of the system. However, scenarios do not give information on which future is likely or desired.

9.2.1   Why Do We Need Scenarios?

The transformation of a system requires future-oriented system knowledge. Not only are current elements of a system and their interdependencies of relevance but also possible future changes. New elements could enter the system, and established ones could lose their significance. Also the interrelationship between the elements could change, or new ones may be established. To control a system transformation, i.e. to identify and implement suitable pathways, strategic thinking is highly recommended, in particular in the case of complex systems. Strategic thinking requires particular tools and instruments for predicting and assessing alternative futures and pathways to achieve the desired future.

Prediction and controllability of the future were the main pillars of economic policy in the first half of the twentieth century, not only in socialist countries. For example, Japanese economic development after World War II was based on a "plan-oriented market economy system" (Johnson 1982). The Japanese Ministry of International Trade and Industry (MITI) acted

Fig. 9.1 Scenario filter funnel
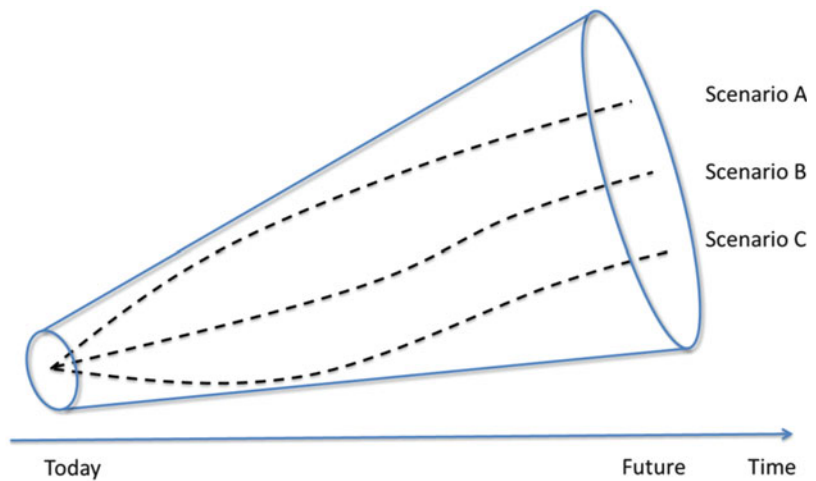
like a central planner, yet was not always successful (Johnson 1982; Jansen 2002). Prediction has to be understood as a statement about an uncertain future based on experience or knowledge. In that context, prediction is achieved through rigorous mathematical or statistical methods (Rescher 1998). Controllability describes the requirement that a system must be controllable so that the system status can be changed to a desired status. The target status of a system is achievable by manipulating the relevant control variables (Kalman 1963). The "planning optimism" collapsed in the aftermath of the first oil crisis in 1974 (Wack 1985).

Despite this "planning optimism" after the Second World War, future-oriented activities started in the RAND Corporation in the 1960s (Wack 1985; Schwartz 1996), evolving from a prognostic approach to the future to a scenario-based one (Grunwald 2002). In contrast, a scenario approach denies the possibility of predicting and controlling the future due to the complexity of systems and the impossibility of capturing all relevant elements and their interdependencies. Therefore, scenarios aim to describe a "space of possibilities" of future developments, meaning that different futures are possible, at least from today's perspective (Fig. 9.1; Kosow and Gaßner 2008). If the future is not predictable and controllable, strategic

thinking is of utmost importance. Scenarios are a useful tool to support such thinking.

Scenarios describe complex pictures of the future that are seen as plausible. Plausible means that the described future may happen given today's knowledge of the system under investigation. But plausibility does not mean the described future is likely or even desirable. Scenarios can include extreme situations, which are seemingly not likely yet plausible. Common to all scenarios is the use of consistent assumptions about possible future developments, leading to divergent futures (Grunwald 2002; Kosow and Gaßner 2008).

9.2.2 Functions of Scenarios

Scenarios fulfil several functions, which can also overlap:

- Knowledge function
- Communication function
- Goal-setting function
- Strategy-forming function

From a scientific point of view, the knowledge function is considered the most important. It has two aspects. The first aspect is a consequence of using scenarios for analysing systems. Scenarios

can help improve knowledge about the cause-and-effect relationship within systems and the kind and degree of possible consequences of developments, decisions, or policy measures. Scenarios can also help detect unwanted consequences of actions, "blind spots", or even contradictions in decisions or policy measures as well as dilemmas. The latter means different aims cannot be achieved simultaneously. As such, trade-offs between targets may exist. To give an example, intensification of farming that targets the enhancement of yields may contradict the aim of environment-friendly agriculture.

The second aspect stems from the process of scenario building. Scenarios can capture only part of a complex system. The analysed system must be "simplified" by dispensing with irrelevant elements or reducing the complexity of interrelationships between elements to focus on those that provide knowledge for the intended aim. For example, in agricultural economics, model-based scenarios often exclude nonagricultural activities such as forestry (Balkhausen et al. 2008). However, a sine qua non for reducing the complexity is the awareness of what is considered relevant for a particular question and what is not. In this way, scenarios reduce complexity in a systematic and transparent manner to a cognitively measurable level. Specifically, the scenario-building process enables the systematic and targeted integration of different information types, i.e. findings and theses from different disciplines, as well as qualitative and quantitative data. In principle, scenarios also offer the possibility to integrate social objectives, norms or values in a transparent way (Kosow and Gaßner 2008).

In cases where scenarios are developed in collaboration with stakeholders, they can serve as an integrative platform for players from different fields and thereby help structure topics and arguments. This can assist the parties involved in better understanding their respective positions or interests and working out priorities. It can also encourage them to discuss the subject matter in a long-term perspective (Havas 2014). Thus, scenarios have a communication function that should not be underestimated.

From a more strategic perspective, scenarios can also assist in the development or specification of goals (goal-setting function). They can help stakeholders to reflect on their perspectives or positioning (Minx and Böhlke 2006). In addition, they can provide orientation in planning processes (strategy-forming function), such as testing the robustness of strategies and comparing different alternatives (Kosow and Gaßner 2008).

9.2.3 Scenario Approaches

As there are different ways of thinking about the future and possible paths towards it, there are many approaches to structuring scenarios. Most commonly, they are subdivided into three types, and this subdivision points to central differences in their development and application. According to Börjeson et al. (2006), these can be designated:

- Predictive
- Explorative
- Normative scenarios

Predictive Scenarios
Predictive scenarios are typically used to forecast the most likely future. Here, scenario analysts aim to answer questions like "what will happen in the future?" or "what can be expected?". Answers are typically provided by "just" updating or extrapolating past trends into the future. For example, to predict the production of biofuels in Germany in a specific year, say 2025, it can be assumed that the future growth rate will follow the same trend as, for example, in the last 10 years. Implicitly, this type of scenario disregards any change in market conditions or other relevant decision-making parameters.

It is arguable whether predictive scenarios should be counted as scenarios at all. Strictly speaking, they strongly resemble predictions, which by definition are not scenarios. Instead, although relatively cumbersome, they should be called "scenario-like forecasts". Scenarios

assume that different futures are possible, whereas forecasts tend to look for the right future. The early developers of scenarios such as Kahn and Wiener (1967) would certainly have refused to use the term scenario here.

We include predictive scenarios here for pragmatic reasons. First of all, it makes the distinction between the other two types, i.e. explorative and normative scenarios, clearer. Additionally, the concept of scenarios is often extended to predictive approaches by practitioners. A reference scenario is often constructed on the basis of trend extrapolation, representing how the world would look if everything continued as before. This is often referred to as a "business-as-usual" or BAU scenario. Predictive approaches can also inform investors or managers of expected developments (Börjeson et al. 2006). A BAU or reference scenario can then be compared with other, explorative or even normative scenarios. A reference or BAU scenario is not assigned a probability: a future where everything continues as before is no more likely than one characterized by dramatic changes. In this case, the "predictive scenario" is just one scenario among others.

Explorative Scenarios

Explorative scenarios attempt to show possible futures. It does not matter whether these futures are desired or likely. Analysts use explorative scenarios to answer questions like "what would happen, if …?" or "what is possible?". Here, exploring past trends plays a minor role. The most important step in building explorative scenarios is identifying the main drivers of development of the elements of the system and their interdependencies. Another step is to identify plausible assumptions regarding the development of such drivers (cf. Sect. 9.3.4).

Since these assumptions are based on today's knowledge, it is also possible to consider events that are unlikely or unpredictable but can greatly influence developments. For example, the impact of a comet in 2032 would darken the atmosphere for several years through scattered dust. This could lead to a slowdown in climate change, but it might also have a long-lasting impact on

agriculture: lower yields and higher food prices could intensify the competition for arable land. Wild cards or black swans, as they are often called, need not be so drastic. A breakdown of the EU Common Agriculture Policy or the successful market penetration of a new product type, e.g. in vitro meat, is also a possible wild card.

Whereas predictive scenarios have their starting point in the present, this is not obligatory for explorative scenarios. For example, scenarios considering the impacts of future political intervention have a year in the future as starting point (Börjeson et al. 2006).

Explorative scenarios are particularly suitable for long-term horizons of 20–40 years. Statements on these timescales are exceptionally difficult when they concern complex systems with a high degree of uncertainty, such as the bioeconomy.

However, the surroundings in which these aims are to be achieved are not static over time. Examples of dynamically changing factors are, on the demand side, population, dietary habits, preferences for biogenic and non-biogenic products, and income and on the supply side technological progress within the food, agricultural industry and forestry-based industry, energy conversion technologies, and both traditional and innovative material processing industries.

To capture the uncertainties and identify a "space" of possible futures, it is recommended to build several, distinctly differing scenarios. An example is presented in Table 9.1 (see also Box 9.1).

The focus of each scenario is on the potential cause-and-effect relationships. The addressees can then develop strategies for action or rethink existing strategies. Political or business strategies can be tested for their robustness. For example, one could be concerned with the question of how biomass would develop as an energy carrier if strong societal demands ("saving the cultural landscape") hinder cultivation of energy plants.

Depending on the purpose of a scenario, it may also be important to vary both external and internal factors (Börjeson et al. 2006). External factors are those that cannot be influenced by actions of the principal, e.g. the government or

Table 9.1 Example for distinct scenarios

Scenario	Demand for biomass for material and energy	Biomass supply	Remark
Scenario A: bio-modesty	Low growth rate	Medium growth rate	–
Scenario B: bio-boom	High growth rate	High growth rate	Supply of biomass matches demand
Scenario C: bio-scarcity	High growth rate	Medium growth rate	Supply of biomass cannot match demand

Based on Kovacs (2015)

Note: The study discusses possible future developments of a European bioeconomy up to 2050

company. Internal factor are those that can be influenced by the principal. Varying these factors makes it possible to test the robustness of action strategies in the context of alternative developments, which consequently allows flexible and adaptive strategies to be identified. Likewise, an organization can be sensitive to signals ("weak signals") that indicate important future changes (Börjeson et al. 2006). By varying internal factors, strategic scenarios can be developed (ibid.). The starting point is formed by various action strategies, which are tested for their possible effects and subsequently compared.

Box 9.1: Possible Futures Towards a Wood-Based Bioeconomy: A Scenario Analysis for Germany (Hagemann et al. 2016)—An Example

In this analysis, six key influencing factors relevant for the future development of a wood-based bioeconomy in Germany were identified through literature research and expert survey, including:

– Biomass Availability and Forest Structure
– Globalisation and Global Economic Development
– Impulses from Energy and Climate Policy
– Supply and Demand for Wood
– Willingness to Pay for Bio-based Products
– Innovation Along the Wood Value Chain

Four scenarios were elaborated, each assuming a different development of the influencing factors:

Scenario 1—"Government as a driver": The government is sustainability oriented and drives the transformation towards a bioeconomy. Companies remain cost oriented, consumers reluctant to bio-based products, and voters not convinced.

Scenario 2—"Trend towards sustainability": Similar to Scenario 1, the government is sustainability oriented, yet in contrast to the first scenario, consumers and producers perceive the long-term trend towards greater sustainability as an opportunity.

Scenario 3—"Keep going": Due to the government's and society's affinity with traditional values and established structures, no risks are taken to implement changes.

Scenario 4—"State as obstacle": Whereas companies are confident in new technologies and society shows some commitment, the government is reluctant to implement supporting conditions.

For further scenario analyses, see:

• Kovacs B (ed) (2015) Sustainable agriculture, forestry, and fisheries in the bioeconomy. A challenge for Europe.

The definition of *normative scenarios* makes the difference to explorative scenarios clear. Norms and values are deliberately and clearly identified along with their target, i.e. a specific future. They try to answer questions such as "How can a specific target be reached?" (Kosow and Gaßner 2008; Schippl and Leisner 2009). Although the target is typically desirable, this is not a sine qua non for a normative scenario. Normative scenarios are often used for major social transformations, such as the transformation towards a bioeconomy, but can also be used for less complex questions. The target situation may not necessarily be different from the current one. In the case of environmental issues in particular, maintaining the present state may be desirable, e.g. preventing climate change or conserving biodiversity.

A typical form of normative scenarios is called "backcasting". Here, targets are selected that are to be achieved at a certain point in the future (see Fig. 9.2, No. 1). This could be, for example, increasing the share of renewable energies in Germany to 80% by 2050. In a second step, the chances of achieving the target under the current conditions or trends are analysed using forecasts (No. 2 in Fig. 9.2) or a business-as-usual scenario. If these trends are not sufficient to achieve the target, a third step is carried out: "images" of the future that would achieve the goal are sketched from today's point of view as consistently as possible (No. 3 in Fig. 9.2). Then, in a last step, paths that can lead to these future images are identified (No. 4 in Fig. 9.2), and precise options for action to attain the goal are formulated. This is a very comprehensive and inclusive approach, which can result in the elaboration of far-reaching policy measures.

Some authors also follow the approach of Alcamo (2008), who speaks of anticipatory scenarios (sometimes called "prescriptive scenarios"), which have their starting point in the future. Table 9.2 summarizes the presented types of scenario approaches.

The classification outlined here is often helpful in structuring scenarios. Of course, they are rarely found in a pure form when put into practice. For instance, explorative scenarios are usually not entirely without normative assumptions. Deciding which parameters are important and thus to be included or varied necessarily involves a certain evaluation.

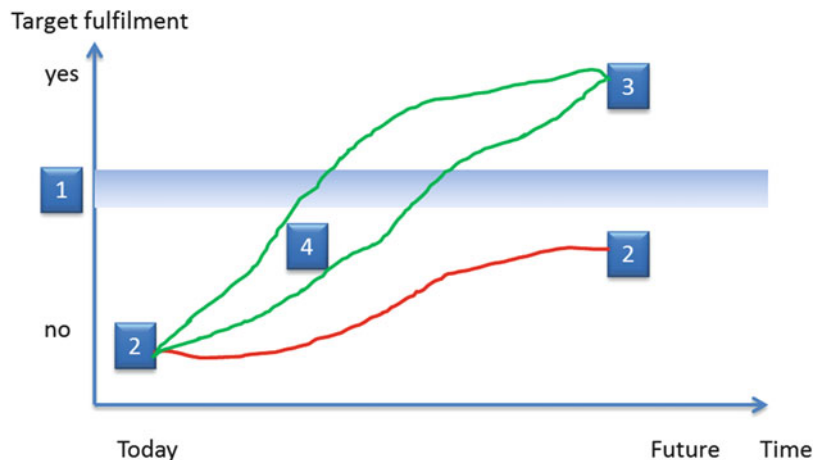**Fig. 9.2** Backcasting in four steps (based on Höjer and Mattsson 2000)

Table 9.2 Scenario approaches

	Predictive scenarios	Explorative scenarios	Normative scenarios
Characteristic questions	What will happen? What can be expected?	What could happen, if...? What is possible?	How can a specific target be reached?
Aim	To predict the most likely future	To analyse possible futures	Analysis of paths to reach the target
Method	Extrapolation of trends	Identification of main drivers	Backcasting

Table 9.3 Advantages and disadvantages of qualitative and quantitative scenarios (Alcamo 2008)

	Qualitative scenarios	Quantitative scenarios
Advantages	Can integrate the views of different experts or stakeholders Can describe very complex systems Well-written "storylines" can provide an understandable and appealing communication about the future	Deliver figures that are needed for certain questions Assumptions can be transparent and accessible (i.e. underlying numbers, equations, coefficients) Many scenarios use models that have already been published and have thus been scientifically evaluated Can be used to test the consistency of qualitative scenarios
Disadvantages	The scenarios are often based on "mental models" which may be difficult to understand Their underlying assumptions are difficult to identify, analyse, and test When it comes to the achievement of concrete target values, qualitative approaches by definition cannot offer figures	The figures suggest a high precision of the results which can obscure the fact that they are estimates Model-based scenarios are often based on a very large number of assumptions that are difficult to verify (especially for non-specialists) For practical (e.g. no available data) and methodological reasons, models cannot depict systems completely. The process of reducing the complexity is driven by an available model and not necessarily by the challenge Data availability, as well as methodological reasons, tends to model only well-documented system interrelations

In the literature, scenarios are also distinguished by the way they are described and identified: in so-called qualitative scenarios, characterized by the use of narratives ("storylines"), and so-called quantitative scenarios, typically associated with algebraic models presenting futures or transformation paths as numerical data (see Sect. 9.3). This classification can also be applied to the types of scenarios described above.

Both types of scenarios have advantages and disadvantages. These are summarized in Table 9.3.

The choice between qualitative or quantitative scenarios depends on various factors, like the availability of data or the user/client demands.

For example, the discussion on energy transformation is dominated by model-based (quantitative) scenarios (see, e.g. Appelrath et al. 2016). A good example of bioeconomy-related qualitative scenarios is OECD (2009) (Kovacs 2015; Hagemann et al. 2016).

In practice, however, quantitative and qualitative approaches are often mixed. Narratives are underlined by numbers or serve as a starting point for more complex modelling. A highly systematic combination of qualitative and quantitative approaches can be found in Alcamo (2008), who describes his approach as a story-and-simulation (SAS) approach (Weimer-Jehle et al. 2016).

Although future-oriented scenarios can be a strong tool to structure discussions or to support decision-makers, they have a substantial disadvantage. Scenarios do not offer truth claims in the sense of scientific knowledge. For the latter it must be possible to verify (to confirm) or falsify (reject) a statement (Popper 2008). This is, of course, not possible for developments that do not yet exist because they occur in the future. On one hand, scenarios reflect today's perception of future problems and today's knowledge on how challenges can be overcome. On the other hand, scenario builders are exposed to stakeholder representatives or lobbyists, who try to influence the future of political decision-making processes through specific future images. This could involve deliberately constructing futures that are opposed to other futures and suggesting decisions that benefit particular interests. In this context, Brown et al. (2000) refer to contested, i.e. controversial, futures.

This disadvantage can backfire on scenario-based decisions if the underlying scenarios are perceived as worthless, resulting in them being dismissed as arbitrary speculation. However, it is essential to have a meaningful perspective at the political or business level—and this is one of the central objectives of scenarios—that scenarios are not completely arbitrary but based on comprehensible validity criteria. Decisions require more reasoned and thus not purely speculative future images. But this is not a trivial challenge.

As mentioned before, validity criteria or scientific methods are not available. In the literature, a few central criteria have been proposed for the assessment of scenarios (Grunwald 2002; Kosow and Gaßner 2008):

- Plausibility: Described developments must be plausible, but not necessarily likely or desirable.
- Consistency: Images of the future as well as paths to the future should not contradict one another.
- Comprehensibility/traceability: The level of granularity/aggregation of the scenarios should be determined by the aim of the scenarios, i.e. they should not be too complex or too detailed.

- Selectivity: Alternative scenarios should represent different future designs. The different designs should not just be the result of a "mere" variation in a certain parameter; rather they should present different complete blueprints of a future.
- Transparency: Relevant assumptions and decisions (and the criteria used) should be disclosed. A high degree of intersubjective comprehensibility can be achieved through reflection on the procedure.

These criteria are valid for all scenario types, irrespective of whether they are qualitative or quantitative. As mentioned before, they can only help to reduce the arbitrariness of scenarios; they cannot be used to reject assumptions—in marked contrast to other methods, for example, those used in science. That means the findings of scenarios do not deliver "accurate" scientific knowledge. This peculiarity is often not emphasized enough when scenarios and their results are referred to. Scenarios are applied when uncertainty is involved.

9.2.4   Scenario Building

There are various ways of building scenarios; this section lists the most important steps (Heinecke and Schwager 1995). The following references reflect only a small part of the available literature: von Reibnitz (1988), Godet and Roubelat (1996), Schwartz (1996), Schwab et al. (2003), Börjeson et al. (2006), and Bishop et al. (2007). Note that the approaches presented in the literature may differ in detail, e.g. by focusing on particular steps or aggregating others.

The approach presented here is comprised of eight stages:

1. Problem analysis: The central objective of this stage is to provide a sufficiently precise identification and description of the problem to be investigated, explained for all persons involved in the scenario analysis, and to facilitate common understanding among the stakeholders. This serves as starting point

for the definition of individual steps in subsequent stages.

The problem analysis should include:

- A statement on the purpose of the scenarios to be developed, differentiating between normative and explorative objectives. This influences the definition of relevant target variable(s).
- A statement on the timeline over which the scenarios are to be developed.
- A statement on the operational (e.g. the company) or sectoral (e.g. bioeconomy) framework in which the analysis is to take place.
- A statement on the spatial framework, i.e. whether the investigation applies to a city, a region, or the world.

The four aspects mentioned are, of course, closely related and mutually interdependent.

2. Analysis of the framework: The objective is to specify the basic conditions in which the scenarios are to be developed and thus to define the final framework in which the scenario analysis is to take place.

The analysis of the framework (sometimes also problem field), comprises four steps:

- Specification of the system boundaries: Which elements of a system, e.g. sectors, should be included.
- Determination of the relevant descriptors: Descriptors are values that characterize or describe partial aspects of the problem, for example, population trends, developments of market prices, and events.
- Classification of the descriptors with regard to the control possibilities.
- Identification of system interdependencies.

3. Assessment system: To evaluate the results of the scenario analysis, an assessment system has to be implemented. This may be fairly simple with just one indicator, e.g. income growth rate, or it may be an elaborated system with numerous indicators. The purpose of the scenarios determines the choice of indicators.

4. Scenario building (in the narrow sense of the word): Scenarios are developed based on the results of stages 1 and 2. Scenario development can be divided into five steps:

   (i) Identification of critical and noncritical descriptors: Noncritical descriptors are parameters whose changes in the planned timeline are considered to be relatively precise in their foreseeability. It is assumed that there will be no breaks in chronological trends or that any changes are relatively foreseeable (Heinecke and Schwager 1995). Noncritical descriptors can also include parameters considered unimportant for the overall system but which should be considered in the analysis for other reasons such as consistency. For example, in many scenarios the growth rate of gross domestic product is seen as noncritical. Critical descriptors, in contrast, are characteristics whose development is either regarded as essential to the analysis of the problem or whose future changes are subject to unforeseeable breaks in trends.

   (ii) Definition of the development of noncritical descriptors: in most cases, simplified forecasts.

   (iii) Definition of the development of critical descriptors: Since the influence of critical descriptors is per definition crucial to the system, an elaborated analysis of possible developments is highly recommended. Therefore, these descriptors also form the core of any sensitivity analysis.

   (iv) Formation of (raw) scenarios.

   (v) Compilation of complete (end) scenarios.

5. Scenario implementation: Each scenario developed in stage 4 describes a consistent set of assumptions regarding the development of the descriptors. These are inputted into the analysis framework defined in stage 2, to determine their effects on the causal problem or target variable(s). If the analysis framework

is captured, for example, by an algebraic model, the descriptors correspond to the exogenous variables of the model. Specifically, the effects of the descriptors on the target variable (s) can be calculated using an adequate solution algorithm. The results can be understood as alternative representations of future images with respect to the overall system under investigation.

6. Scenario evaluation: The future images determined in stage 5 are assessed in several steps:
   - Plausibility check: Are the findings plausible? For example, a negative gross demand is not plausible.
   - Consistency check: Are the findings consistent with respect to the assumptions? For example, if a close, positive correlation between demand and income is postulated, a decreasing demand with increasing income is inconsistent.
   - Sensitivity analysis: How robust are the findings with changes in relevant parameters?
   - Assessment of the findings, using the assessment system defined at stage 3.
   - Analysis of possible implications: This depends on the type of scenario. In exploratory scenarios, additional effects not covered in the scenario can be investigated. For example, an exploratory scenario could examine the effects of an increasing share of algae-based biogas on the future electricity mix, but not its effect on agriculture. The analysis of possible implications might address the latter aspect. In normative scenarios, questions on the implications of these prospects for the potential decision-maker may arise, e.g. which tools are available to the decision-maker to realize the respective future image? Which internal corporate groups or stakeholders should be taken into account by the decision-makers in order to identify the relevant instruments and to make their implementation more concrete?

7. Recommendations for action: If scenarios are used in decision-making contexts, the findings from stage 6 are expected to lead to recommendations for action. In contrast, if the analysed scenarios are solely for orientation purposes, i.e. explorative scenarios, information on possible developments is systematically generated. This stage can be dispensed with if the project is not based on a concrete decision-making situation.

   The recommendations strive to identify action alternatives for the decision-makers in order to solve the original challenge. They should include suitable instruments for solving the problem and describe their design. To increase the success of decisions, analysis of possible implications should also identify relevant groups, including stakeholders, who should be included in the decision-making process.

8. Summary: The results should be summarized in a form understandable to the client/ addressee and enable them to make decisions where necessary. The summary should contain:
   - Central results
   - Central assumptions
   - Essential recommendations for action

The eight stages should not be understood as strictly sequential, but rather to be carried out according to specific requirements in the literature. This means that at each stage, newly acquired knowledge should be used to examine whether the chosen approach or assumptions, as well as the results from previous stages, need to be revised or adapted. Figure 9.3 demonstrates the interrelation between the individual steps.

In practice, a clear separation of the individual stages is not always possible. The correct order of stages 1–3 is arguable, and it soon becomes apparent that this is a chicken-and-egg situation. Ultimately it is up to the developers to decide at what stage they want to start or if they can even combine stages 1–3. For new participants, we would recommend separating these three stages
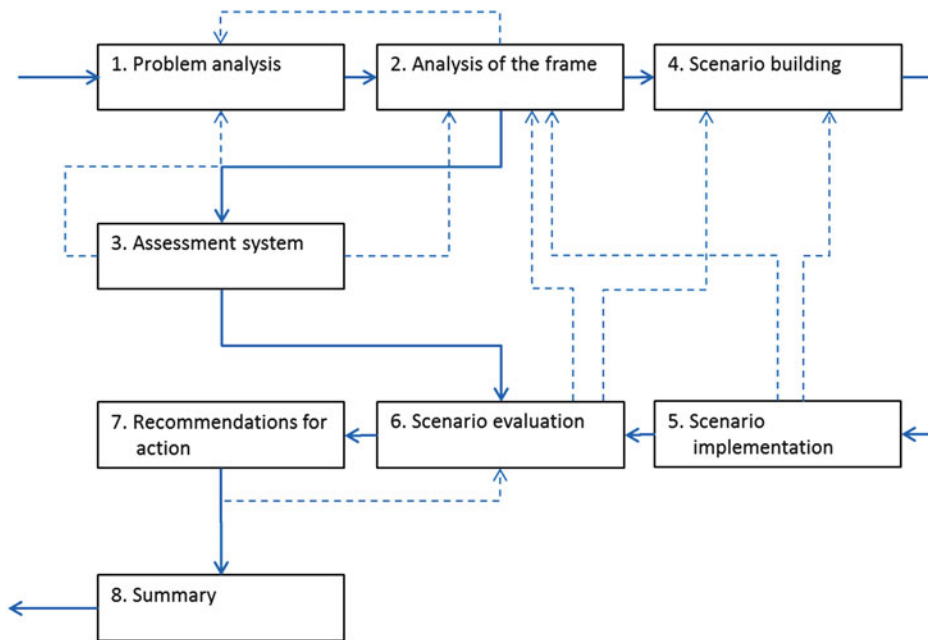
Fig. 9.3 Stages in scenario building

in order to keep track. Likewise, the order shown above has proven advantageous. By analysing the problem and the framework precisely at the beginning, the defining of utopian or irrelevant goals can be avoided. A reiterative approach can, however, also be recommended.

Finally, it should be emphasized once again that, in the creation of scenarios, it is extremely important to make clear what is being done where and for what reason. Even if in practice there are many deviations and special cases (see, e.g. "backcasting"), the structure shown here helps to make practitioners aware of the necessary steps and available options.

9.2.5 Conclusions

Scenarios can be a strong instrument in structuring discussions and supporting decision-makers, in particular if the object is the transformation of complex systems. But scenarios are not a panacea in the formation of a desired future:

- Scenarios are not forecasts or predictions; this also applies to reference or BAU scenarios. Scenarios never represent true future events.
- Scenario findings always depend on the initial conditions or "ingredients" with which they are created. Their selection always depends to a certain extent on the priorities set by the scenario builder. Therefore, they are never completely objective or impartial. As such, the initial conditions should remain as transparent as possible.

Scenarios do not offer a truth claim in the sense of scientific knowledge. The criterion of the falsifiability of scientific theories is not applicable. Therefore, it is necessary that scenarios fulfil the criteria discussed above (see Sect. 9.2.3).

9.3 Integrated Model Approaches: Identifying the Ways and Means

Models can make valuable contributions to the analysis of potential scenarios for a future bioeconomy. Due to the extensive

interdisciplinary approaches and the high degree of economic integration in bioeconomy models, the requirements are however enormous. A central challenge for holistic modelling is that both economic and ecological connections and future social developments must be taken into account. Currently, there is no modelling approach that can cover all aspects of a developing bioeconomy (O'Brien et al. 2015).

Several studies have considered the necessary structure and requirements of model networks for the assessment of a prospective bioeconomy, including the project "Systems Analysis Tool Framework for the EU Bio-Based Economy Strategy" (SAT-BBE) within the EU 7th Framework Programme. This study elucidated the dependencies in modelling and showed how existing model approaches can contribute to the analysis of the entire "bioeconomy" complex. The study indicated that existing model

approaches can be linked, however, some deficits and gaps in mapping the entire bioeconomy still have to be closed (van Leeuwen et al. 2015).

A multitude of drivers, such as demographic development and consumer preferences, influence the development of a bioeconomy (Fig. 9.4). In addition to drivers, societal challenges such as food security need to be taken into account. At the same time, natural (e.g. water, land scarcity) and socio-economic (e.g. education level, labour demand) constraints must also be considered. These data can be used to derive policy strategies for different sectors and protected subjects (van Leeuwen et al. 2015).

Based on this network of coherencies, it is possible to derive both substantive requirements and modelling levels for a comprehensive model network of the aforementioned relationships. The competition for land and forestry biomass for food, feed, fuel, and fibre can thus be represented
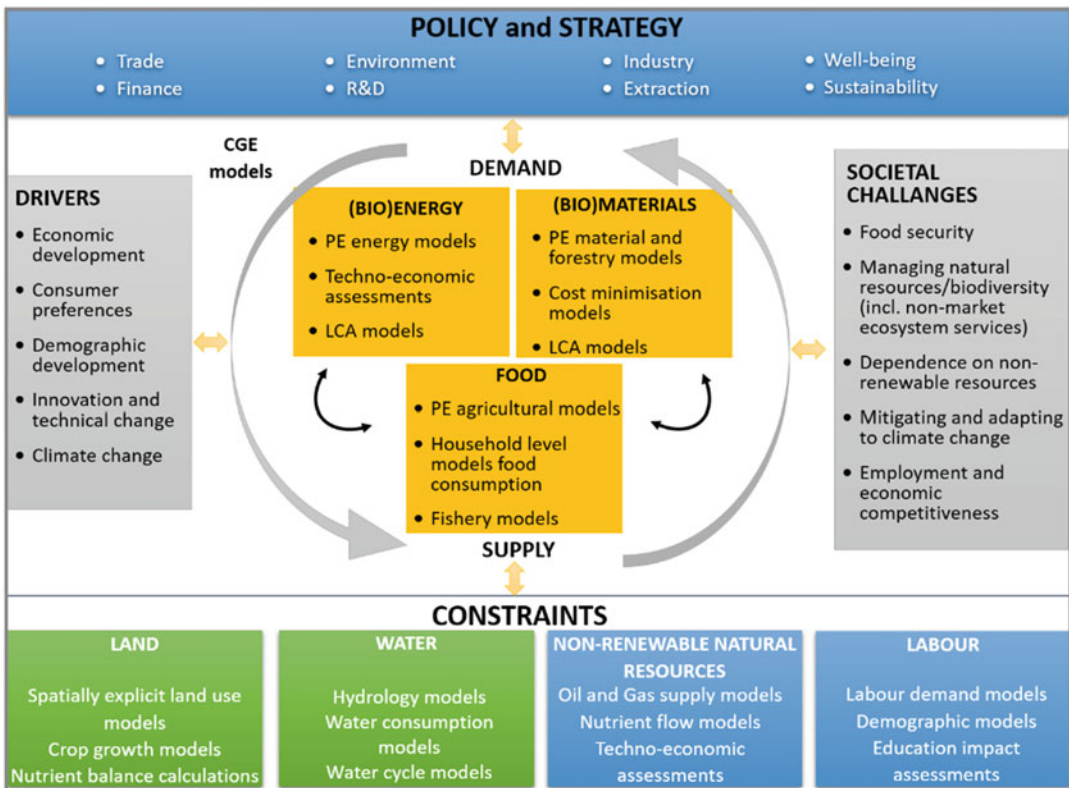

Fig. 9.4 System overview of the framework of a developing bioeconomy (based on van Leeuwen et al. 2015)
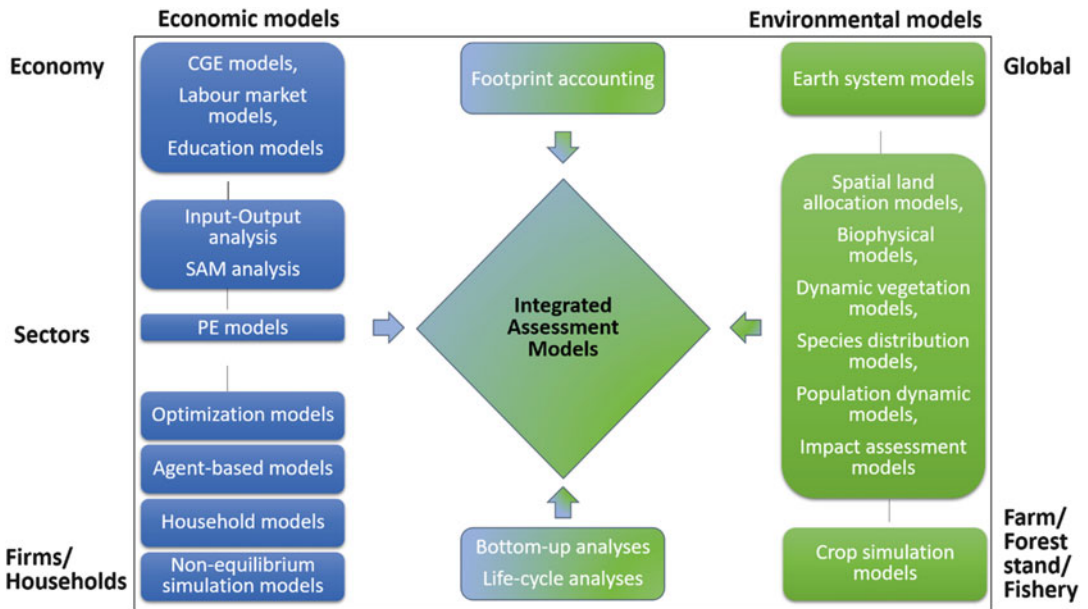
Fig. 9.5 Overview of model types and groups when evaluating development pathways of a bioeconomy (based on van Leeuwen et al. 2015)

by computable general equilibrium (CGE) models. However, a more precise assessment of possible competitive pressures should also be done at a sector or farm level. Since an increase in demand for biomass in a bioeconomy, e.g. in an industrialized country like Germany, will always be associated with a global impact, such impacts must be included in addition to the national perspective (Fig. 9.5).

9.3.1 Economic Models

This section provides an overview of different economic modelling approaches. Although the presented models were not originally developed for the bioeconomy context, they can still be used for modelling biomass supply and demand. The focus is on macroeconomic, computable general equilibrium (CGE) models and partial equilibrium (PE) models as well as bottom-up approaches for detailed analysis of specific questions within a bioeconomy.

Macroeconomic Models
CGE models are based on the general equilibrium theory; an economic theory, in simplified

terms, seeks to explain the balance between supply and demand. These models are often used for trade analysis. PE models are also based on this neoclassical theory, but they focus on a specific market or sector. They are useful in obtaining a more detailed understanding of a particular sector.

1. Examples of CGE models

The *GTAP* (Global Trade Analysis Project) is a global network of researchers conducting quantitative analysis of international policy issues, coordinated by Purdue University in Indiana, USA. It provides a generalized CGE modelling framework along with a comprehensive database used for analysis in other CGE models. The standard GTAP model is a recursive dynamic CGE model. Its main applications are multilateral trade analysis and the effects of trade liberalization. It represents the linkages between sectors such as agriculture and energy and has been extended to the bioenergy field, specifically ethanol, biodiesel, and their by-products; the agricultural residue corn stover; the energy crops switchgrass and miscanthus for second-generation ethanol production; and palm oil

residues (Wicke et al. 2015). The statistical base of a CGE is a so-called social accounting matrix (SAM). A SAM builds on a circular flow conception like input-output approaches and thus could be used independently of a CGE for macroeconomic analysis (cf. Poganietz et al. 2000).

The *MAGNET* (Modular Applied GeNeral Equilibrium Tool) is a recursive dynamic CGE model developed at the Landbouw Economisch Instituut (LEI; Wageningen University and Research, Netherlands) and builds on the GTAP database. It is the succession model of LEITAP (Landbouw Economisch Instituut Trade Analysis Project). It has a modular set-up with modules for mapping the EU Common Agricultural Policy (CAP) and biofuels and evaluates long-term, economy-wide upstream and downstream effects including price (Van Meijl et al. 2006). MAGNET was applied to analyse the macroeconomic impacts of large-scale deployment of biomass resources in the Netherlands (Hoefnagels et al. 2013), the macroeconomic impacts of a bio-based economy in Malaysia (van Meijl et al. 2012), and the global leakage effects of EU biofuel consumption (Smeets et al. 2014). Recently, MAGNET has been extended by additional bio-based sectors such as second-generation biofuels, bioelectricity, biochemicals, and biomass supply sectors for both residues from agriculture and forestry and pretreatments of agricultural residues that are utilized by other sectors (Banse et al. 2014). This extension specifically allows the impacts of developing and implementing new biomass conversion technologies to be evaluated.

2. Examples of PE models

GLOBIOM (Global Biosphere Management Model) is a global, economic partial equilibrium model for the agriculture and forestry sectors with high-resolution representation of global agriculture, forestry, and land-use change. It forms part of an integrated modelling framework at the International Institute for Applied Systems Analysis (IIASA; www.globiom.org). The model encompasses all countries including aggregations into 28 global regions. Its crops and forest sector details are based on physical parameters supplied by the more specialized models G4M for forestry and EPIC (Izaurralde et al. 2012) for agriculture. The global agricultural and forest market equilibrium is computed by choosing land-use and processing activities to maximize the sum of producer and consumer surplus subject to resource, technological, and policy constraints. GLOBIOM can be linked to energy models through information on macroeconomic indicators and bioenergy demand. The latter is split into first-generation biofuels, second-generation biofuels, bioenergy plants, and direct biomass use for energy. Issues analysed by GLOBIOM include the competition for land supply between agriculture, bioenergy, and forestry; examples are land-use change impacts of bioenergy policies, climate change mitigation policies, and food-versus-environment trade-offs (Kraxner et al. 2013).

CAPRI (Common Agricultural Policy Regionalised Impact) analysis is a spatial PE model focussing on the agricultural sector in Europe. It was developed to evaluate ex ante impacts of the EU Common Agricultural Policy and trade policies on agricultural production, income, markets, trade, and the environment from a global to regional scale. CAPRI can analyse a broad range of policy measures while taking agro-environmental impacts into account. The comparative-static economic model is split into a supply module and a market module. The supply module consists of independent non-linear programming models that represent activities of all farmers at regional or farm-type levels as captured by the economic accounts for agriculture. The market module delivers prices used in the supply module and enables market analysis at global, EU, and national scales as well as welfare analysis. The link between the supply and market modules is based on an iterative procedure. These modules are linked to regional CGE models for each European country with a specific focus on rural development measures under the second pillar of the CAP (www.capri-model.org).

ESIM (European Simulation Model) is a global PE model for the agricultural sector that represents agricultural production, various processing activities, and demand for agricultural products as well as international net trade (see Box 9.2). With its comprehensive model of the EU CAP, it is used to analyse EU agricultural and trade policies. It covers the EU member states and accession countries, the USA, and the rest of the world (the latter as one aggregate). It comprises the processing of oil seeds for biodiesel production and of cereals, sugar beet, and sugar cane for bioethanol; the production, use, and foreign trade in biofuels; and the production and use of side products (oil seed cakes, gluten feed) in livestock production (Deppermann et al. 2014). Recently, it has been extended to include lignocellulosic biomass such as miscanthus and poplar.

EFI-GTM (European Forestry Institute-Global Trade Model) is a multi-product, multi-regional PE model for the global forest sector. It integrates increasing forest resources, timber supply, wood-using industries (e.g. carpentry, pulp, and paper industries), and demand for forest products and wood-based energy as well as international trade in forest products. The model specifically calculates periodic production, consumption, import and export quantities, and product prices for forest sector products. It has global coverage with a focus on Europe. It also allows detailed impact analysis of the forestry sector and detailed trade impacts through bilateral trade flow. It has been used to address issues such as increased investments in forest plantations in Asia and South America, increased demand for bioenergy, impacts of carbon emission prices and fossil fuel prices on the use of wood biomass for energy, and impacts of trade policies and forest conservation policies.

Economic Bottom-Up Models
There are a variety of bottom-up models that can answer a wide range of questions within the framework of an overall bioeconomic complex. For the most part, these models analyse very detailed technologies and processes as well as the behaviour of different players such as farms or energy plants. Furthermore, a large number of models exist that work at different spatial levels. This is of particular interest when analysing the availability and supply of biomass along with the related economic and ecological effects as well-defined system boundaries are included. These models can provide detailed insight into specific issues. However, as a rule, bottom-up models are not capable of producing indirect or induced effects (e.g. price responses, competition, replacement effects, and technological or structural changes) beyond their relatively narrow system limits (Wicke et al. 2015). For such purposes, they would need to be linked, for example, to the CGE or PE models mentioned above. Several examples of economic bottom-up models for different sectors and disaggregation levels are provided below:

1. Examples of agro-economic supply models

The model approaches presented here are suitable for simulating the adaptation reactions of farms or regions to changing political or technological conditions. Their methodology predominantly consists of mathematical linear or non-linear programming models that result in the quantity of agricultural products produced under relevant conditions. They are often developed in research projects for specific issues or locations only and are not used after the end of the project (Janssen et al. 2010). However, the following models, which are exemplary of the large number of existing agricultural bottom-up models, are firmly established in research facilities and have been continuously used and developed for various economic and environmental assessments of agricultural systems. Some farm-based models can be used at regional or sectoral levels with the help of projection methods.

FSSIM (Farm System Simulator) is an optimization model that maximizes the total gross margin under a set of resource and political constraints. It is a component-based framework

with modules for mapping farmer objectives, risk, calibration, and both agricultural and environmental policy instruments as well as current, alternative, and future production activities. The model is designed as a generic bioeconomic farm model. Through its flexible design, it can be used for a variety of climate zones, soil types, farm types, research applications, and data sources (Janssen et al. 2010; Louhichi et al. 2010). For instance, FSSIM has been applied to 13 regions in the EU and to different farm types. FSSIM is also used to analyse the farm level (Ewert et al. 2011) within SEAMLESS ("System for Environmental and Agricultural Modeling; Linking European Science and Society"), an integrated modelling approach (see Sect. 8.4.3).

EFEM (Economic Farm Emission Model) simulates agricultural production on micro (farm)- and meso (regional)-levels. It is a supply model based on static linear programming. The prices for producers, production costs, and capacities for typical farms are exogenously determined. The model considers the most important agricultural production methods in animal and plant production in Germany. On a regional level, it differentiates with regard to yields, intensities, productivity, and costs. To display the required farm model capacities, either data from the Farm Accountancy Data Network (FADN) or survey data can be used. The model also calculates greenhouse gas emissions, other nitrogen fluxes, and carbon balances from agriculture production (Schwarz-v. Raumer et al. 2017). It has already been linked to various biophysical models (see Sect. 8.3.2) (Neufeldt et al. 2006; Wagner et al. 2015). For analysing possible bioeconomy development scenarios, it can be used in conjunction with other models in the "Competence Network Modelling the Bioeconomy" (see Box 9.2).

FARMIS (Farm Modelling Information System) is a comparative-static programming model for farm groups based on datasets from FADN. It maps agricultural production activities in detail at the farm level and accounts for competition between farms on important factor markets. Using a positive mathematical programming procedure, the model is calibrated to a respective base year. The use of aggregation factors enables

the representation of agricultural sector production (Deppermann et al. 2014). It can currently be applied to the analysis of agricultural sectors of Germany, Great Britain, the Netherlands, Hungary, and Switzerland. Together with the CGE and PE models of the Thünen Institute, it has also been used to model the linkage between agricultural, energy, and agricultural markets in the context of the bioeconomy (Banse et al. 2016).

2. Examples of techno-economic optimization models for biomass supply chains

Biorefineries and bioenergy production sites often present two challenges that are difficult to combine in models. On the one hand, they require a certain plant size in order to operate economically. On the other hand, larger plants need a significant feedstock and associated supply area. Logistical costs often play an important role in the cost-effectiveness of such plants. For this reason, more and more optimization models have been developed in recent years to determine possible sites for bioenergy combustion plants or biorefineries. Two such models are presented below.

BeWhere is a spatially explicit, techno-economic engineering model for optimizing renewable energy systems. It is a mixed linear programming model and is used at the International Institute for Applied Systems Analysis (IIASA) to evaluate localization, size, and technology of the renewable energy system (IIASA 2017). It can be applied at both national and EU level. In the area of biomass use for energy purposes, BeWhere minimizes the costs of the complete bioenergy supply chain, including biomass harvest and transport, conversion, transportation, and delivery of biofuel and heat and electricity sales. A great variety of feedstocks can be considered in the model. Nevertheless, the focus is on second-generation biofuels, and therefore crop residues, forestry waste, and lignocellulosic industrial waste are included (Wetterlund et al. 2013).

BiOLoCaTe (Biomass value chain integrated Optimization for Location, Capacity, and Technology planning) is also a mixed linear programming model that is used to optimize biomass

supply chains. This techno-economic assessment includes supply, logistics, and conversion processes and is based on achievable profit from revenue generated from selling either electricity and thermal energy or bio-based materials. The model results can be used to support decisions in regional planning of biomass-based value chains (Rudi et al. 2017). In contrast to BeWhere, it is not only used for evaluating renewable energy systems but also bio-based material production systems. Currently it is only applied in Baden-Wuerttemberg (a federal state in southwest Germany) but can also be adapted to other regions or countries. Like EFEM, it is used for holistic analysis of possible developmental paths of a bioeconomy in the "Competence Network Modelling the Bioeconomy" (see Box 9.2; Schultmann and Rudi 2017).

3. Example of an energy system model

The energy sector is generally integrated either through CGE models or with the help of PE models. An example of a disaggregated, bottom-up model is *TIMES PanEU* (Pan-European TIMES model), which has been applied in several analyses of the European energy system (see Box 9.2). The model minimizes an objective function by representing the total discounted system costs from 2010 to 2050 and assumes perfect competition among various technologies and pathways of energy conversion and supply. It is a multiregional model that covers, at the country level, all sectors connected to energy supply and demand. TIMES PanEU includes all countries of the EU28 along with Switzerland and Norway. In addition, both GHG emissions and pollutant emissions are included by incorporating process-specific emissions.

The model is flexible in terms of regionalization (for instance, within Germany), and both energy and nonenergy bioenergy use options in the energy system or modelled technology pathways. A detailed analysis of competition between alternative technologies and energy use of biomass paths can be taken into account for the overall economic perspective (Blesl et al. 2012; Deppermann et al. 2016).

9.3.2   Ecological and Biophysical Models

The transformation from a petroleum-based economy to a bio-based economy will inevitably lead to increased demand for agricultural and forestry biomass. This may result in increased biomass production in certain countries and on a global scale. However, this may also lead to a conflict of interest with environmental and nature conservation. As such, not only the economic aspects but also the ecological effects of a developing bioeconomy should be taken into account. Since agricultural and forestry production is systematically linked to the use of natural resources, a large number of models have been developed over the past few decades to simulate these environmental effects.

Biophysical models are process-based models that represent biological, geological, and chemical processes in environmental systems. These include, but are not limited to, crop growth and soil physical models. Some models examine a wide range of environmental impacts of agricultural and forestry management systems. Others also examine different scales from plot to farm, region, and global levels. Some models were originally developed and validated for smaller area units but were extended to regional and global scales due to greater demand for agricultural and environmental policy assessment measures. At the beginning of 2000, substantial political and scientific focus was put on evaluating agricultural greenhouse gas emissions, which resulted in numerous economic models being combined with biophysical models at a regional level. In particular, soil greenhouse gas emissions could be clearly captured, and at the same time, the costs of possible mitigation options could be assessed. For example, the models CAPRI and EFEM mentioned above were linked with the biophysical models DNDC (DeNitrification-DeComposition) and EPIC (Environmental Policy and Integrated Climate) (Neufeldt et al. 2006; Britz and Leip 2009; Schwarz-v. Raumer et al. 2017). EPIC is also integrated into various integrated assessment models (Kraxner et al.

2013; Zessner et al. 2017) and is described below as an example of the functions of biophysical models.

Examples of Ecological and Biophysical Models

EPIC (Environmental Policy and Integrated Climate) was originally developed at the US Department of Agriculture to study the effect of agricultural production on erosion and soil productivity. Since its creation, it has been further developed by several research institutes into a comprehensive terrestrial ecosystem model for simulating numerous ecosystem processes that can also take a wide range of land-use management options into account (e.g. tillage, harvest, fertilization, irrigation, drainage, liming, burning, and pesticide application). The main components in EPIC are crop growth, weather simulation, hydrology, nutrient and carbon cycling, soil temperature and moisture, soil erosion, tillage, and plant environment control (Izaurralde et al. 2012; Balkovič et al. 2013). When combined with economic models or model networks to assess agricultural and forestry biomass production, EPIC can be used to address two major research questions: the effect of changing environmental conditions on biomass production, e.g. forecast crop yields impacted by climate change ((Kraxner et al. 2013; Kirchner et al. 2015), and the impacts of different management options for biomass production on the environment, e.g. erosion, nitrogen leaching, or soilborne greenhouse gas emissions (Schwarz-v. Raumer et al. 2017).

The soil-crop model *CERES-EGC* functions in a similar way to EPIC. It has been used for more than 20 years to investigate the environmental effects of crop cultivation such as nitrate leaching, soil greenhouse gas emissions, and ammonia and nitrogen oxides (Durandeau et al. 2010). CERES-EGC can also be used to predict yields of the most important agricultural crops (Mavromatis 2016). Both models can be used at field and regional scales.

LPJmL (Lund-Potsdam-Jena managed Land) is an example of a Dynamic Global Vegetation Model (DGVM) that was designed to simulate the global terrestrial carbon cycle as well as the response of carbon and vegetation patterns to climate change. It was developed by a consortium of scientists from the Max Planck Institute for Biogeochemistry in Jena, the Potsdam Institute for Climate Impact Research, and Lund University. To study the role of the biosphere in the anthroposphere, it is crucial to represent both natural and agricultural ecosystems in a single, internally consistent modelling framework. The model is designed to simulate composition and distribution of vegetation as well as stocks and land-atmosphere exchange flows of carbon and water for both natural and agricultural ecosystems. Using a combination of plant physiological relations, generalized empirically established functions, and plant trait parameters, the model simulates processes such as photosynthesis, plant growth, maintenance and regeneration losses, fire disturbance, soil moisture, run-off, evapotranspiration, irrigation, and vegetation structure. Consequently the model facilitates integration of agricultural systems into the global climate-vegetation system (PIK 2017; Bondeau et al. 2007). Within the framework of the PIK model network, LPJmL is linked to MAgPIE (Model of Agricultural Production and its Impact on the Environment) and REMIND, a global multiregional model incorporating the economy, climate system, and a detailed energy sector.

9.3.3 Land Use and Biodiversity in Life Cycle Assessment

Although a bioeconomy strives to be sustainable, associated technologies consume resources and cause environmental impacts. These technological, process-, or product-related impacts can be calculated and compared using the standardized life cycle assessment (LCA) method. Specifically, in order to obtain a holistic view of the product chain, a life cycle perspective is necessary. A more in-depth description of LCA is given in Sect. 8.3. In this chapter, the focus is on integrating land use and biodiversity aspects into LCA.

The importance of land and its related ecosystem services gained attention through the Millennium Ecosystem Assessment (MEA). It was

conducted from 2001 to 2005 under the auspice of the United Nations. The aim of the MEA was to assess the consequences of anthropogenic changes in ecosystems on human well-being and to provide the scientific basis for needed measures for a sustainable use of ecosystems (Millennium Ecosystem Assessment 2005). The study underscored the global dependency of mankind on nature with ecosystem services as the basis for a healthy and safe life. As about 50% of earth's land area is strongly affected by mankind (Hooke et al. 2012), land use has enormous effects on ecosystem services and biodiversity. Therefore, in order to cover all relevant environmental impacts of a product or process, land-use aspects that impact ecosystem services and biodiversity ought to be integrated into analysis methods such as life cycle assessment. In recent years, methods for considering impacts on ecosystem services and biodiversity have been successfully developed and applied in LCA.

Fundamental to integrating effects on ecosystem services and biodiversity in LCA is the concept of occupation and transformation of land use. The term occupation means the situation of a studied patch of land, while it is used. It is assumed that there is no change in ecosystem quality during the entire period of use (e.g. 20 years for a short rotation coppice). Occupation is expressed as the level of ecosystem quality during use compared to a specific reference quality. In contrast, the term transformation defines a change in ecosystem quality of a studied patch that occurs between the initial quality of the ecosystem and the end quality after the use phase ends and the land is regenerated.

LANCA® (Land Use Indicator Value Calculation Tool) is an approach to integrate the impacts on ecosystem services into LCA (Beck et al. 2010; Bos et al. 2016). It was developed at the University of Stuttgart, Department of Life Cycle Engineering (Baitz 2002) and has been applied in many projects. In LANCA®, indicator values are calculated that describe the environmental impacts of land-intensive processes on various ecosystem services, which are then integrated into the life cycle assessment. The following environmental impact categories are calculated

on the basis of (geo-)ecological methods: erosion resistance, mechanical filtration, physicochemical filtration, groundwater regeneration, and biotic production. In 2016, LANCA® 2.0 was produced which allowed for GIS-based calculations of the five land-use-related environmental impact categories. Country-specific characterization factors (CF) can now be calculated (Bos et al. 2016).

The *biodiversity potential field approach* (Lindner 2015) understands biodiversity as a fuzzy object. Existing approaches integrating biodiversity aspects into LCA often focus on species richness of landscape types (Koellner and Scholz 2007, 2008; Baan et al. 2013; Chaudhary et al. 2015). According to the biodiversity potential field approach, biodiversity of a patch of land is defined as a function of several parameters, e.g. structural elements, pesticide input, nutrient balance, biomass utilization rate, and crop diversity. The biodiversity potential field of a region thus describes the relationships within that region. For aggregating impacts of global value chains, weighting factors are defined for the respective regions. These are based on the species richness of the regions and the rarity of the species occurring in the regions. The result of this approach is a universal measure of biodiversity that is sensitive with regard to the most important influencing factors.

LCA has a bottom-up perspective and can give evidence for the environmental performance of a product. Therefore, the results of a LCA can serve as input data for other models such equilibrium models:

- If models like EFEM for regional supply of agricultural biomass are, for example, extended to the aspect of land use and biodiversity through a linkage with LANCA®, comprehensive statements can be made about the supply of agricultural biomass and its environmental impacts.
- By integrating LCA results, e.g. for impact categories such as climate change and acidification, in partial equilibrium models such as ESIM, these models can be strengthened by the LCA results as environmental statements

on the shifting effects of changing demand for certain agricultural products can be drawn in addition to economic statements.

9.3.4 Integrated Assessment Models

The idea of integrated assessment models (IAMs) is to design and assess interactions between human activities and the natural environment. To do so, models that depict either anthropogenic or (bio)physical systems are coupled. The envisaged integration can refer to the analysis of coherent problems and to the integration of stakeholders, disciplines, processes, and models at both temporal and spatial scales. This can be done in interdisciplinary and integrated approaches as stand-alone models or in a framework of multiple, coupled models that focus on various topics or scales and which originate from different disciplines (Wicke et al. 2015). All models described above can be part of such a modelling collaboration.

> **Integrated Assessment Models (IAMs)**
> IAMs describe and assess the interactions between human activities and (global) environmental processes. They include descriptions of socio-economic systems as well as environmental systems and the interactions between the two.

The main advantage of IAMs is they overcome the limits of models that focus on specific topics, e.g. on the agricultural or the energy sector, without considering impacts of human activities on (bio)physical systems. By coupling different models, IAMs can cover a range of different disciplines and fields of research including economics, energy analysis, agriculture analysis, and biophysical science, thus bridging the economic, social, and environmental dimension of bioeconomic developments. With respect to a bioeconomy, IAMs could elucidate implications for both energy systems and natural systems such

as land and water use and interactions with global cycles such as carbon in an integrated manner.

Models can be linked in several ways to achieve an integrated assessment (Wicke et al. 2015):

- Align and harmonize input data for the different models and levels of aggregation, e.g. the number of economic sectors and scenario definitions.
- Align and harmonize core assumptions: if this is not possible, at least a systematic comparison of results and sensitivities should be carried out to reveal differences between models to a greater depth.
- Link models: integrate model ranges by using results from one model as inputs for another model (one-way data exchange) or iterating inputs (two-way data exchange) through partial integration via a simplified version of one model in another model, or full integration solving models simultaneously is also a way.

An alternative distinction within linking models is often made between soft links, i.e. where models are connected exogenously through transferring outcomes of model runs from one model to another, and hard links, i.e. where models directly exchange information and are solved iteratively so that the solutions are internally consistent between the models. Soft links allow for more components to be included but require careful coordination of data flows to avoid unnoticed inconsistencies between models. In contrast, hard links allow for more consistent representation of the systems yet increase complexity and reduce transparency (Leimbach et al. 2011).

One well-known transdisciplinary IAM is IMAGE (Integrated Model to Assess the Global Environment), developed at PBL Netherlands Environmental Assessment Agency. IMAGE simulates global environmental change induced by human activities and can be applied in the DPSIR framework for reflecting a systems analysis view on the relationship between
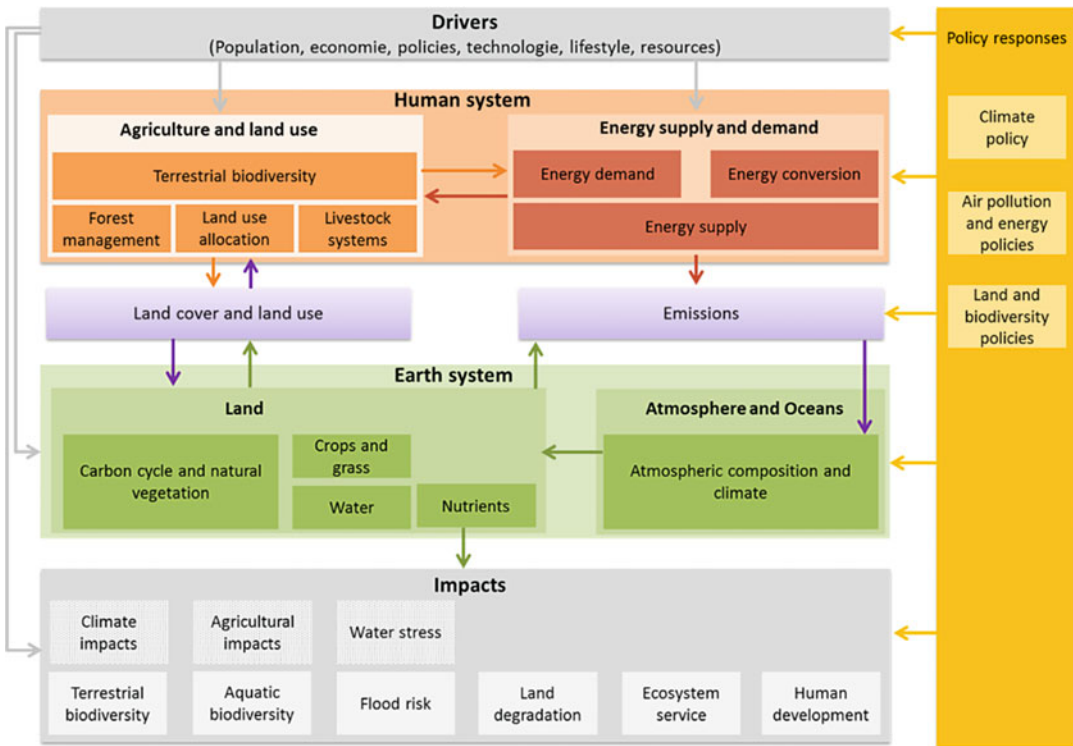
Fig. 9.6 The IMAGE 3.0 framework (http://themasites.pbl.nl/models/image/index.php/IMAGE_framework)

environmental system and anthropogenic system. The framework consists of drivers, pressures, state, impact, and responses (Smeets and Weterings 1999).

IMAGE combines a number of existing models such as MAGNET (agricultural economics), GLOBIOM (biodiversity), and FAIR (climate policy). The objective of IMAGE is to model the long-term dynamics of global change caused by demographic, technologic, economic, social, cultural, and political factors (Fig. 9.6).

Table 9.4 lists a comprehensive overview of previously described model approaches. The application areas of the different model approaches along with their strengths and weaknesses make clear that only the use of multiple approaches at different modelling levels will provide a holistic view of a complex bioeconomy. This can be achieved by either coupling otherwise independent model approaches or within the framework of an IAM.

Box 9.2: Competence Network Modelling the Bioeconomy

The competence network modelling the bioeconomy established within the Bioeconomy Research Programme Baden-Württemberg is another example of a modelling network aimed at integrated assessments bridged across disciplines and scales. Besides the models EFEM, ESIM, TIMES PanEU, BiOLoCaTe, and GaBi a LCA Software, the competence network integrates the CGE model PACE and the material flow model CarboMoG. The models in the network are linked at various stages (Fig. 9.7). All models were harmonized with regard to defined bioeconomy scenarios. The goal of the competency network was to compare and evaluate both the direct and indirect economic, material, and ecological effects of different

(continued)

Box 9.2 (continued)

biomass usage pathways. Such a framework allowed for comparing economic costs and benefits of different bioeconomy scenarios. Economic benefits resulted from the improvement of environmental quality or the further development of certain sectors of the economy, while economic costs arose from income losses as well as increased biomass imports, which could have impacts on the environment in other parts of the world.

Table 9.4 Overview and characteristics of the most important model approaches for holistic modelling and assessing a bioeconomic development path (based on Wicke et al. 2015)

|	CGE models	PE models	Bottom-up analysis	IAMs
Application	Economy-wide impacts of biomass and bioenergy policies, including subsequent effects on land-use change and GHG emissions induced by these policies Indirect substitution, land use, and rebound effects due to multiple sectors and production factors	Sectoral impacts of bioenergy policies on agriculture, forestry, land-use change, energy system, and GHG emissions	Wide variety of specific (technical) aspects of biomass production, conversion, and use Validation of other studies with a broader scope, such as PE and CGE models and IAMs	Bioenergy resource potentials under different assumptions (incl. sustainability criteria) Possible contribution of bioenergy to long-term climate policy Impacts of bioenergy policies on global land use, water, and biodiversity
Typical timeframe	Short to long term	Short to medium term	Short to long term	Long term
Strengths	Comprehensively covers both economic sectors and regions to account for interlinkages Can explicitly models limited economic resources Measures the total, economy-wide, and global effects of bioenergy policies (including indirect and rebound effects)	Covers in detail sectors of interest with full market representation Explicitly represents biophysical flows and absolute prices Usually gives more details on regional aspects, policy measures, and environmental indicators	Gives detailed insights into techno-economic, environmental, and social characteristics and impacts of bio-based systems	Integrates various relevant systems into one modelling framework Possibility to analyse feedbacks between human and nature systems and trade-offs and synergies of policy strategies Built around long-term dynamics
Limitations	Level of aggregation may mask variation in underlying constituent elements Scope of CGE models necessitates simplified representation of agent choices, in particular favouring smooth mathematical forms and reduced number of parameters required to calibrate the models Often none or few explicit representations of quantities for biophysical flows	Optimizes agent welfare, but only for the sectors included in the model Does not consider macroeconomic balances and impacts on not-represented sectors Needs large number of assumptions for long-term projections	Indirect and induced effects outside the boundaries of the study not included, i.e. interactions with other sectors often deliberately ignored	Too high a level of aggregation or systems too complex Unsuitable for short-term assessments Requires large number of assumptions (and communication of these to the public)
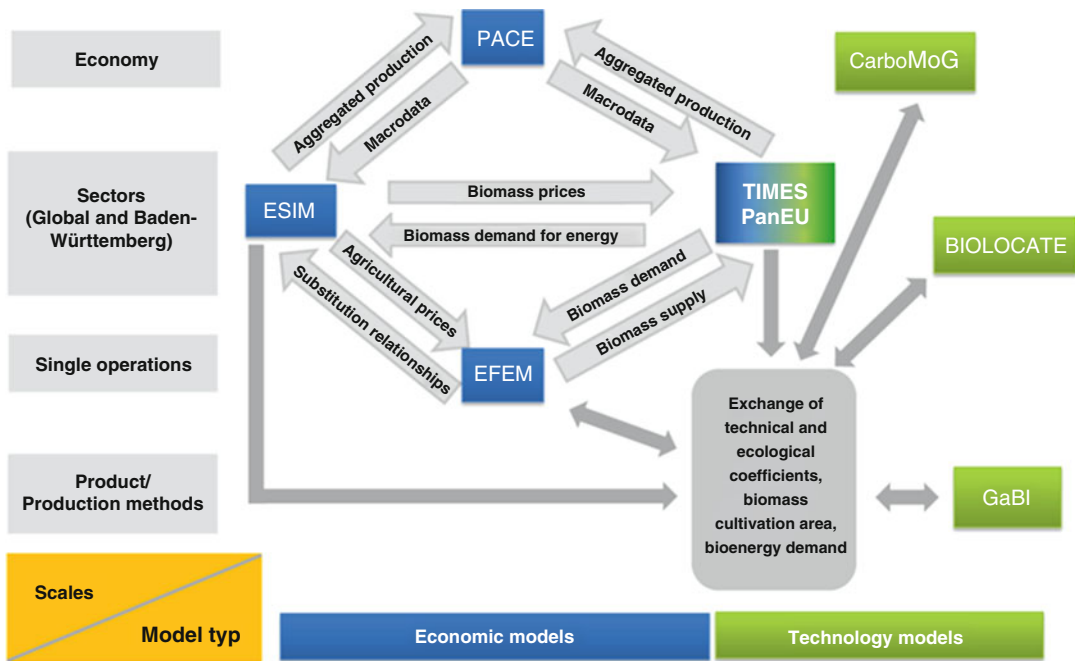
Fig. 9.7 Competence network modelling the bioeconomy Baden-Württemberg

9.4   Conclusions: So What?

Increasing scarcity of fossil and metal resources in addition to the tremendous impacts on both the natural environment and human health during extraction as well as during manufacturing, use, and disposal requires a radical change in current strategy of generating wealth and income. Yet, as described, transforming an economic development strategy at first and consequently the entire economy must be done in a rather complex environment. Not only are the underlying economic and physical interdependencies not always known in detail, but also the preferences, interests, and ideas on how a future economy should work differ widely in society. Therefore, instruments are required to help society elaborate the "best" future.

In this chapter, two widely used instruments are presented: scenarios and algebraic models. Whereas scenarios strive to help "reveal the possible trails" of possible futures, models are used in "identifying the ways and means" of future paths. In practice, models are often directly linked to scenario exercises.

Scenarios can present alternative futures based on assumptions and modelling results from diverse tools like CGE models, IAM models, and environmental profiles of products from life cycle assessments. As scenarios cannot present the realistic future, they instead give an indication of how the transformation would look like if certain objectives were reached as well as what could happen if there was no change in lifestyle. A discussion of scenarios or modelling results is especially helpful in raising awareness of possible unwanted and unsustainable development.

Through interdisciplinary networking, exchanging, and production of data, various models can be made more consistent thus resulting in more harmonized and realistic results. The higher the quality of the input data in representing possible and achievable future conditions, the more realistic is the output of the scenarios in question. That means discourse in analytics, science, politics, business, and society on objectives and system boundaries of the global future is required in order to draw a common picture of our future.

Within this chapter, the following was provided: an overview of the scenario approach, different types of models and their possibilities, and both the chances and limits of using scenarios to forecast the future. There are many models and assessment tools that can be used to support the transition process to a bioeconomy when using their modelling results in scenarios. Our selection of included models is only a small part of the variety of modelling approaches and is certainly not the be-all and end-all. Modelling approaches and theories are undergoing constant development and must also be constantly reconsidered.

All the presented models, tools, and different types of scenarios can assist in picturing possible futures and can support transitioning to a bioeconomy. However, by no means can they predict the future. Still, the transformation cannot take place through maintaining the present, Western civilization lifestyle nor by expanding this lifestyle to the whole world. Humanity must change its way of life to reach a sustainable bioeconomy.

Review Questions

- The expectations for a viable bioeconomy are enormous. What drivers and societal challenges affect a developing bioeconomy? Thus, what difficulties result for a holistic modelling of future scenarios of bioeconomy?
- A main disadvantage of scenarios is often seen in their shortcoming to offer verifiable scientific knowledge. Why could this be seen as a disadvantage in the building of a strategy for a viable bioeconomy? Are there any approaches to limit the risks resulting from the above-mentioned disadvantage?
- Börjeson et al. (2006) differ between three types of scenarios. How the three types could be characterized? Under which understanding predictive scenarios are not mere predictions? Why explorative scenarios could need normative elements?

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