Section One

Towards Sustainability

Chapter 1

General Introduction

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Prelude: Why this book?

Agriculture is increasingly entering the headlines: soaring food prices, increasing hunger and food export limitations have become common elements of major news stories. They have also dominated major public and political debate, be it in industrialized or in developing nations, and with reason. Production and consumption of food and feed have been changing, while development of biofuels has soared following stimulating measures, mainly in the EU and the USA. The reasons for these supporting policies are diverse: the notion of limited fossil fuel availability in the future (peak oil), the wish to end the dependency on oil-exporting countries, or to reduce greenhouse gas (GHG) emissions. Although biofuel production is not the only (or even the most important) reason for observed changes in crop availability or food prices, biofuels have taken a large share of the blame. While this might not be correct, it is understandable. Large-scale application of biofuels competes with food production and might enhance hunger and poverty through complex interactions of policy changes, investments and price changes. It might, further, lead to enhanced deforestation.

Policies aiming at mandatory biofuel blending have had a large impact on biomass production and utilization. Although not all changes in prices, land use and deforestation can be attributed to biofuels, they certainly have played a role, thus providing an important reason to study the rapid changes in biofuel production, the way it has been steered by policy and the impact (desired as well as undesired, intentional or unintentional) this has had. But the introduction of biofuels, although very important, should not be treated as an isolated issue. It is an element of a wider development, where fossil feedstocks are replaced on a larger scale, for more purposes and in more parts of our economy. This development might, therefore – in the long run – have even larger implications on the way we live, consume and produce.

The chapters in this book identify a number of replacement processes that are occurring more or less in parallel. This book is devoted not to biofuels alone. It discusses a series of technologies that facilitate the replacement

of significant amounts of fossil fuels by biomass. Adoption and implementation of these technologies will alter the way we live. Together, they will allow us to produce, trade, transport and consume in a more sustainable way; that is, without massive use of fossil oil or gas. These technologies have many similarities, and their development is interlinked. Their combined implementation can have a large impact. It might change our fossil economy to a 'biobased economy'.

What are these technologies? Why are they important? What will be their impact? This book will provide an answer to these questions. It will describe changes in biomass conversion and use that together have an impact larger than that of an isolated technological change. Driven by innovation, boosted by recent policies implemented in industrial countries, they might cause important changes in crop production and utilization. What is steering these policies, and why is it so difficult to assess their implications? What impacts might the technological changes have (on production processes, on food availability and on society as a whole)? How can we make sure that we move in the desired direction? All these questions will be discussed in this book.

Why this book

There are several reasons to devote a book to biobased economy. First, implementation of a biobased economy can impact the way we live. While individual changes that are involved can have a considerable impact, their *aggregated* effect is expected to be much larger. Consider, for example, unrest caused by biofuel production (allegedly causing major food price increases) to what would happen if biomass would, on top of that, also be used to produce large amounts of bioplastics or chemicals. But the impact would not necessarily all be negative. The production of valuable biopharmaceuticals, biochemicals or biomaterials would not require the amount of price support currently given to biofuels. Application of biorefinery, in combination with enhanced use of by-products and waste, would, further, reduce the demand for feedstock and the impact on commodity prices. The potential of an integrated use of biomass, finding high value applications and combining them with effective use of by-products and waste, can only be identified when its development is studied coherently as is done here.

A second reason for this book is the perception that the replacement of fossil fuels by biomass is part of a long-term development: the search for more efficient, more advanced and more sustainable production. This development is steered by a series of drivers: the search for economic gain, for reduced dependency on limited resources and for cleaner production. For whatever reason, it is a continuous process, the analysis of which

requires a long-term perspective. If one wants to assess the potential (or risk) of this transition process, it is important to appreciate the long-term perspective and continuous efforts that are made for technological and logistic improvement. Which brings us to the third reason for this book: clearly, if a new technology must fit in an existing system then it is not the innovation as such, but its application that determines its impact. While a given technology – be it conversion of lignocellulosic material into transportation fuels, or a new chemical compound produced from biomass – in theory can be applied in a similar way in many countries, in practice its application is co-determined by local conditions in a given country: technological infrastructure, feedstock availability and prevailing economic and social conditions. Thus, it is not sufficient to study just the technologies. If we want to assess their potentials or impact, we also need to study the conditions in which they will have to fit.

Understanding the complex production and consumption processes of our societies requires a full comprehension of the different forces that steer their development. Changes rarely occur by accident and if they do, responses by society are by no means accidental. People interact in many ways: as consumers, producers, labourers, through voting, producing, buying, selling, via media and so on. It is tempting to limit our analysis (including a range of technological developments to be implemented in different sectors of the economy, affecting production and consumption and, in an indirect way, the basis of our lives, i.e. air, land and water, biodiversity, but also economic growth, income distribution, poverty and hunger) to a merely technical specification, describing innovations and the way they could be applied in production processes.

This would only offer, however, restricted insight. It would ignore the way (new) production processes impact on society as a whole. It would also underestimate the impact that societies have on innovation, that is, the way markets, policies but also public opinion steer technological changes. This is demonstrated by the reactions biofuels provoked around 2007 and early 2008. While production in the USA, EU and other industrial countries still was relatively low (replacing only 2 or 3 per cent of transportation fuels of the 6 to 10 that is pursued) debates on its desirability and undesired by-effects (on food prices, hunger and biodiversity loss) became so vigorous that in some cases governments' replacement goals were reduced and criteria introduced to safeguard sustainability and social desirability.

This book will consider a number of technological innovations that make possible the enhanced replacement of fossil fuels by biomass. Its main objective is to explore the potential of a biobased economy, and determine how to steer its implementation in such a way that it leads to an optimal environmental, economic and social performance. Implementation of the

necessary innovations will be a long-term process that will probably require decades. This transition process will require changes at different aggregation levels, local, sectoral as well as national, and affect legal, social and moral practices of society. We will study the transition as a whole, assessing not the impact of individual technical innovations, but the aggregated effect of their combined implementation.

This book will present the following:

- A description of transition processes, and the way system changes can help to solve sustainability problems.
- State-of-the-art overviews of major biobased technologies related to the use of biomass in producing biofuels, biogas, biomaterials, biochemicals and (to a lesser extent) electricity and heat.
- Steering processes in which producers, consumers, non-governmental organizations (NGOs), markets and political parties, together, determine how biobased technologies are implemented.
- Country studies showing how ex-ante conditions determine the way in which the potentials of a biobased transition can be realized.

In this book we define biobased economy as the 'technological development that leads to a significant replacement of fossil fuels by biomass in the production of pharmaceuticals, chemicals, materials, transportation fuels, electricity and heat'. This definition defines a number of changes in technologies that might differ in character, but have one thing in common: they facilitate a significant replacement of fossil energy carriers by biomass. Biobased economy refers to technological changes that allow significant replacement of fossil fuels in a way that is beyond traditional applications.

Replacing fossil fuels

A transition towards a biobased economy thus involves implementation of a combination of technologies: some new and some already known. New technologies are based on breakthroughs in biomass conversion or use, while existing technologies might find new applications. Whether old or new, we have already discussed why these technologies should be analysed together. Before we do this analysis, let's see why a biobased economy would be useful. One of the rationales for its implementation is that it can help to reduce use of fossil fuels, thus:

- limiting the dependency on fossil fuels and its exporters;
- facilitating a diversification of energy sources;

- achieving a reduction of GHG emissions;
- providing options for regional and rural development in both developed and developing countries.

These reasons are briefly discussed below.

Reason 1: limiting dependency on fossil fuel exporters

Industrial countries are trying to reduce their dependency on oil imports. This holds especially for the USA and is partly explained by the fact that oil exporters are organised in, and operate under, a cartel: the Organization of the Petroleum Exporting Countries (OPEC). While the formal objective of OPEC has been to stabilize the oil market, it has also been successful in maintaining oil prices at a rather high level. The wish to reduce the dependency on oil-exporting states is further explained by the fact that many of them are located in the Middle East, adding to political and military tensions, and some of these states are suspected of supporting terrorism. Since the '9/11' attacks on the World Trade Center in 2001, increased attention to international terrorism has helped to pave the way for an evolving bioenergy strategy in the USA. This strategy was formalised in 2007 and recently confirmed.

There are, however, other geopolitical reasons to limit dependency on oil-exporting countries. One of them is that the Russian Federation seeks to use its position as a major oil exporter for political leverage in regional political disputes with its neighbouring states. Another, is that Indonesia, the largest Islamic state, is not very positive towards the interests of industrialised states. Oil exporters, finally, often show a (perceived) lack of democratic values, many being run by dictatorial (sometimes military) regimes.

Reason 2: diversification of energy sources

Most industrialized countries are not just trying to reduce their dependency on oil exporters but also their dependency on fossil oil as a whole. While fossil oil has been available in sufficient amounts at reasonable prices for decades, its position now has become more erratic. Apart from political tensions related to production (and export) of oil, doubts have been cast on the availability of fossil oil as *the* major energy source for the decades to come. It is argued that future oil production will be limited by declining reserves as well as by the technical challenges of extracting oil from increasingly adverse oil fields. Others, however, point to discoveries of new stocks that could be brought into production at acceptable prices. While the resolution of this 'peak oil' debate remains unclear for a while, many welcome a diversification

of energy sources which could help to bring down energy prices, limit risks of political blackmail and increase innovation in energy production.

Several alternatives to fossil fuels have been suggested. In the last half of the 20th century, extensive efforts were made to generate nuclear energy while large investments were made in water power. More recently, solar and wind energy have been promoted. Bioenergy, or energy made from biomass – an ancient energy source that has been used for millennia and still is extremely relevant in less developed regions of the world – recently made a comeback. Together with other renewable energy sources (solar, wind and hydraulic) it might be used to diversify the energy portfolio as a way to reduce dependency on fossil fuels.

Depending on their location, economic development, natural resources and political system, countries have developed alternative strategies for renewable energy. Countries with large river systems might opt for large-scale hydraulic power projects (Brazil, China). A few of the largest industrialized countries (USA, Soviet Union, France and the UK) developed nuclear power, a path followed by some of the less developed nations. Solar energy, although pursued in many countries, has not, so far, become a significant source of energy. Bioenergy as major modern energy source was developed mainly in Brazil. Starting with oil price booms in the 1970s and early 1980s, Brazil implemented large-scale investment programmes for the development and implementation of bioenergy.

Reason 3: reducing GHG emissions

Solar, wind and hydraulic energy, and more recently bioenergy, have also been promoted for another reason. Since sustainability and sustainable development became part of the political vocabulary, after being introduced by the Brundtland Commission in the early 1990s, policies have been implemented to stimulate sustainable energy production. Later, analysts introduced the concept of climate change. While climate change sometimes also is translated as a call for nuclear power, the usual focus is on renewable energy sources (solar, wind, hydraulic and bioenergy). Combating climate change became a more important element of the political agenda after the signing of the Kyoto Protocol in 1997. Since then, a range of measures has been identified, and implemented, to reduce GHG emissions (mainly carbon dioxide, methane and nitrous oxide). Although some measures focus on energy saving, increasing attention has been given to the production of renewable energy. The common feature of solar, wind, hydraulic and bioenergy is that they thrive on natural forces. Although all have been actively promoted – usually by coalitions of NGOs, technological companies and political parties – no alternative so far has been able to

dominate the other. Bioenergy came into focus as an option to combat climate change in industrialised countries toward the end of the 20th century, first attempts being made by countries with large natural resources (Sweden, Finland and Germany). The EU embraced bioenergy as an element of its climate change programme in 2005, giving bioenergy a large momentum. Since then, biofuel and other bioenergy programmes have been implemented in a number of other countries, including the USA.

Reason 4: regional and rural development

All the reasons mentioned so far have a political background. They show large similarities, allowing each country to use a specific rationale to underpin its energy strategy. In the USA, for obvious reasons, support for bioenergy is based almost solely on geopolitical arguments. The EU, only slightly less dependent on imports of fossil fuels but with a different geopolitical standing, accepted the Kyoto protocol as a leading principle in its energy policies and focuses equally on diversification of energy sources as well as the combating of climate change. Both have embraced bioenergy as an important, if not the most important, alternative energy source. Other countries are less optimistic. China, showing an unprecedented rate of economic growth but still being on the brink of food deficits, and facing tensions in rural areas, put a hold on the use of food crops for biofuel production. India has taken a position that is equally cautious. The Russian Federation, having ample fossil stocks, the export of which is used to restore some of its former prestige, has not shown much interest in biofuels.

Brazil is the most important example where bioenergy is a major element of the national development programme. Being the world's second largest producer of bioethanol, the country announced an ambitious plan to enhance its ethanol production and stimulate biodiesel production using its potential for soya production. Apart from (macro-) economic reasons, the major justification for this is the contribution of biofuels to regional and rural development.

Bioethanol in Brazil is providing employment to over one million people. In a country lacking a social security system to provide a minimum income, unemployment equates to poverty and deep misery, and these jobs often play a crucial role. It is true that many of these jobs, that is those related to the harvesting of sugar cane, are temporary and work in the cane fields is physically demanding and threatening to health. It has, however, been argued that income from the biofuel industry often helps the poor and deprived to gain a basic income. The President of Brazil has advocated biofuel production as a major impetus for development in some of the poorest regions of Brazil. Other countries could use bioenergy production to generate employment in

underdeveloped regions and bioenergy holds promise especially for rural areas where economic opportunities currently are scarce.

Debating alternatives

Replacing fossils with biomass does not only offer development opportunities in less-developed countries, but it also offers economic perspectives to rural areas in industrialised countries where incomes and employment opportunities have often declined. In the EU, for example, investments related to the production of biodiesel (in Germany, France and Spain), bioethanol (Spain, Sweden, Germany and France) and biogas (Germany the Netherlands) offer new opportunities to areas suffering from declining economic perspectives. The (perceived) scarcity of food further strengthens the position of farmers and rural areas. It is for this reason that farmers have lobbied hard for support to the production and use of biofuels and biogas.

The growing interest in biofuels has provoked a fierce debate among scientists, analysts, politicians, NGOs and other observers. The discussion focuses on its impact on food prices (and consequent effects on the occurrence of hunger), on its contribution to GHG reduction and to deforestation and competition for land and agricultural inputs (fertilizers, water). This has led to a major controversy, with pros and cons of biofuels being presented in many forums. Basically, there are two lines of reasoning.

On the one hand, it is stressed that biofuels (and other elements of biobased economy) allow us to reduce consumption of fossil fuels and dependency on fossil oil exporters. It can also improve future energy availability, and reduce emissions of GHG. Apart from Brazil, where biofuels have already been produced since the 1970s at an industrial scale, notable examples are the USA and the EU, where policies to promote biofuels were combined with efforts to establish new domestic industries based on biomass use. Other countries – especially those with ample natural resources that can gain from rising demand for biomass – have been supporting this development. The main advocates of biofuel production have been farmers' organizations, supported by environmentalist lobbyists and NGOs.

On the other side of the spectrum, many have pointed to the threats posed by massive biomass use for transportation fuels and other industrial uses. Major concerns relate to the use of specific food crops, fuel production thus competing directly with consumers, and to the increased demand for land to satisfy the demand for biomass. This point has been pressed by many NGOs, frequently supported by (some) researchers and politicians. Apart from the competition with food, early critiques focused on sustainability. Impassioned articles were published questioning the reduction of GHG emissions of biofuels.

The debate took another turn when representatives from the UN and the Organisation for Economic Co-operation and Development (OECD) stepped in. When food crop prices started to rise in 2006 and 2007, warnings were raised against further development of biofuel production. One might expect this to change again because prices started to decline towards the end of 2008, mostly reaching their original levels again in 2009. But, as we write, the echo of the price explosion is still vivid in people's minds.

Brazil, having an industry ready to step up biofuel production, and with natural resources to support its need for more feedstocks, has been trying to influence this debate by stressing the potential role of biofuels for development in non-industrialized countries. Referring to his background in the social movement of his country, the President of Brazil explained the contribution of bioethanol production to employment and rural development. Although others, too, have pointed to the potential benefits of local biofuel production for rural development, this element tends to receive relatively little attention in the debate.

Analysing changes

Why is it that the debate on biofuels is so fierce? What makes its controversies so intense? Can biobased technologies be used to end the dependency on fossil oil imports, or will it just bring new dependencies, for example on exporters of biomass? What impact will it have on the position of farmers worldwide?

Generally, the food market evolves from one dominated by surpluses (negatively affecting the position of farmers) to one characterized by shortages (affecting consumers – especially those already poor). Thus, introduction of the biobased economy can impact on poverty and hunger, and it can affect nature and biodiversity. The consequences can be enormous: large investments, both private and public, have already been announced; as well as programmes for economic support programmes and for research. The consequent increases in the demand for biomass (and inputs like land and water) has shifted the aura of biofuels in a very short time from that of a promising renewable energy source to a threat to food, forest and water.

The aggregated impact of biofuels, together with other enhanced use of biomass, is causing an increased need for biomass, land and inputs. The use of food crops in engines goes back to Ford's Model T that ran on ethanol and the invention of the diesel motor using peanut oil. For decades, use of biomass in industrial processes remained by and large constant. With the exception of Brazil and Sweden, use of biomass for transportation fuels was not done on a large scale. It is the introduction of innovations, such as

generating biofuels from lignocellulosic material, which allowed the ambitious biofuel policies formulated in the early 21st century. In the near future, there might be additional policies that aim at further use of biomass for pharmaceutical, chemical or material industries.

Biobased economy is, however, more than a collection of technical developments. As the example of biofuels demonstrates, it is the introduction of an innovation in the real world that usually sets off a series of changes that sometimes are not expected. Existing systems will have to be adjusted, thus requiring or affecting issues of research and technological development, market development and maybe also economic, development and trade policies and so on. Although the reasons for pursuing a biobased economy might seem rather straightforward, the impact of the changes that might be needed can be huge. Pursuing a biobased economy will affect major industrial processes and, consequently, patterns of production and consumption, thus changing the position of (food and input) markets, private companies, consumers and so on.

In the previous section we have introduced the term biobased economy. We saw that there are multiple reasons to pursue a biobased economy, but the impact of its introduction can be so pervasive and complex that some might fear its effects. How will we be able to assess what implications it might have? More important: what can we do to steer the development of a biobased economy in such a way that the end results are acceptable? How can we identify technological development that serves desirable development in the widest sense? What is the best way to steer biobased developments? This will be discussed here briefly.

First, we need to point out that technological changes associated with the introduction of a biobased economy are usually studied in isolation. So far, most attention has been paid to biofuels. Biogas, biorefinery, using biomass to produce pharmaceuticals, chemicals or other materials has hardly received any attention (possibly with the exception of biogas). Although the emphasis on biofuels is understandable, it holds the risk that relevant elements or impacts of technological changes will be overlooked. Studying biobased technologies together does not entail this risk. Instead, it might show how biorefinery can, for example, facilitate combined production of platform chemicals together with biogas or biofuels, thus improving economic and environmental performance. Biobased economy will further allow enhanced use of waste and by-products, thus reducing the overall demand for biomass and its impact on food prices and demand for land.

By analysing the concept of a biobased economy, we can study all technological changes together, rather than studying each of them in isolation. We will do so, reviewing their impact with respect to *all* dimensions of sustainable development: be it environmental, economic or social.

Analyses lacking such an integrated approach are likely to arrive at solutions that are only partially acceptable. Changes that are introduced to, for example, reduce GHG emissions might have consequences for water resources, or impact on biodiversity or lead to social distortions. Thus we might end up with solutions that might be effective for one element of sustainability, but have a negative outcome on other elements. Considering all elements in a simultaneous analysis is more likely to result in suggestions that have the best overall performance. This might restrict implementations of a given technological innovation but, thus, leaving room for other developments, their combined effect outranging that of partial solutions.

One example of this principle is the perspective for a combined biogas cum biofuel production. Optimal solutions for biogas easily lead to the use of energy crops in fermenting units, which is enhancing biogas production. If one could, however, apply such biomass for the production of pharmaceuticals, chemicals or biomaterials, and then ferment the waste streams of these processes, the overall performance would be probably superior although the biogas production itself might be less. There are numerous examples of such system integration, each having their specific merits and drawbacks. Some will be discussed later in this book. In the remainder of this book, we will see that specific elements of crop material that might originally be used for production of biofuels, biogas, heat or electricity might have considerable potential for applications in higher value production chains while the by-products and waste of these high value chains might be used in other, less valuable, chains, thus generating more added value.

Introduction of biofuels and other elements of biobased economy is not an isolated development, nor is it unique in history. None of the drivers pushing their implementation are new. The combination of drivers that currently are identified might, however, be new. In 1973, an oil embargo was applied to the USA, Western Europe and Japan because of their position in the Middle East conflict at the time. Political manoeuvres of OPEC members and the consequent steep rise in oil prices, causing economic problems for industrialized as well as developing countries, provoked all kinds of policies to limit oil dependency. These included programmes to limit energy use (e.g. insulation of housing, promotion of efficient engines) as well as programmes to develop alternative sources of power, including nuclear, hydraulic, wind and solar.

Why is it so complex?

The transition to a biobased economy will have a major effect on society. This explains, at least partly, why people are so concerned about biobased innovations and why the debate on their implementation is so furious. The debate is extremely relevant, but it is far from easy to assess the potential implications of

the biobased transition (one of the reasons why the debate is showing little progress). There are several reasons for this. We discuss four reasons.

First, introducing biobased innovations will have different effects, many of which are interrelated. For example: large-scale biofuel production requires extended production or import of feedstocks, increasing the demand for land and inputs and consequently affecting feedstock availability both at the local and international level. As biomass markets are linked around the world, such changes will, at some point, change conditions for other elements of the food web (affecting production of food or animal feed) or beyond (fibres, pulp and paper, wood). As demand for land will increase, it is likely that this will relate to processes of intensification or land expansion and, finally, deforestation.

A second reason why it is so difficult to identify the implications is the fact that many effects are, in their turn, having other implications. Such indirect effects can, however, only be identified by specialists (and even for them they generally are difficult to link to a specific cause). Thus, while a complete assessment of the biobased transition requires an evaluation of all its effects, be it direct (and clearly visible) or indirect (much less visible), nobody seems to be able to grasp all its implications. This is demonstrated by the debate on the impact of the recent boom in biofuel production on food prices and on indirect land use changes.

The third reason refers to the processes that determine the indirect effects of a biobased transition. Changes in food production and land use are met by reactions on highly specialized markets. Food and other agricultural commodities are traded on complex and volatile markets that are subject to speculation (production depending on highly dynamic and unpredictable weather conditions). Commodity markets also tend to be rather open (although many exceptions exist), linking local effects to global implications. Thus, local changes in food production (e.g. specific weather conditions) can impact global trading in a matter of hours, a process that easily leads to speculation (hence price volatility). Land markets, too, are often unclear and susceptible to speculation.

From the processes that were discussed above, it is clear that the impact of a biobased transition will by no means remain limited to biomass production or conversion alone. It will change the conditions for production of food, feed, fibres, and of many other biomass-related commodities, and affect processes of land use, food distribution and deforestation around the world. These are by no means easy changes, and such impacts are not taken lightly. They touch upon basic social needs and affect all levels of society.

A transition to a biobased economy will, thus, not be limited to agriculture or rural areas. It will affect many aspects of day-to-day life. This is the fourth reason that makes it so hard to assess its impact. Innovations that

might, at first sight, have a technical character, might have implications far beyond their immediate application. As different elements of society are influenced, society as a whole will respond to the impact of their application. This might lead to changes in related policies, and can go as far as imposing restrictions on biofuel production or bans on food exports as recent examples have shown. An overview of the changes in biomass production, commodity markets, consumer behaviour and policy that were provoked by the recent biofuel boom is presented in Table 1.1.

Table 1.1 *First and higher order effects of increased demand for biobased feedstocks: The case for 1st generation biofuels*

	Farmers and biofuel producers	***Markets***	***Consumers***	***Public opinion and policy***	***Research and development/ innovation***
1st order: increased demand for biofuels	1. Increased demand for food/feed crops	2. Reduced crop surpluses			
2nd order: commodity market response		3. Crop price increases			
3rd order: consumer responses			4.Worries on food price increases		Research on extent and causes of price changes
4th order: indirect market effects, policy reactions	5. Crop area expansion, increased input use	6. Price increases for land and inputs		7. Call for action (regulation of crop use for fuels, regulation on land use)	Research on future price changes and land and input requirements
5th and higher order: reactions to lower order effects	8. Improve management (higher input use efficiency). Select more productive crops	9. Replace food crops by non-food crops or crop residues	10. Possible changes in consumption (cheaper food, less animal proteins)	11. Debate on ethics of crop use for non-food. Changes in food/ biofuel policies	Research on input use efficiency, on non-food crops, on changing diets, on (non-) food ethics

An integrated approach

Above we explained that an integrated approach is needed to evaluate the impact of the biobased transition, touching all dimensions of sustainability and simultaneously integrating the related innovations. We have also shown that the impact of such a transition is difficult to assess and might reach unexpected elements of our society. The scale of changes that might occur is huge, and the role that biomass plays in national and international policies is tremendous. This refers not only to sustainability but also to geopolitical and strategic issues.

In this book, we focus on the introduction of a biobased economy as an element of a sustainability policy. This does not mean that other forces steering towards the biobased transition are not relevant; in fact they are very important. The sustainability focus has been chosen because of the similarities between policies aiming to enhance the biobased transition and other sustainability policies. We believe that these similarities are such that, in studying efficient measures to promote the biobased economy, we can profit from lessons learned in the sustainability debate.

Understanding technological developments that facilitate a biobased economy and their impact, and evaluating the options to steer their development to minimise undesired impacts, requires a profound understanding of their background. In this book we study technical innovations against the background of sustainability policies. This will allow us to better understand the interaction between public opinion, policy, markets and technological development.

This book

Central in this book is the insight that the introduction of a biobased economy, that is, the implementation of a series of innovations that facilitate the replacement of a substantial amount of fossil fuels by biomass, is a transition process, requiring changes at the micro, meso and macro level, involving actors active in the production processes where biomass will be implemented as well as many others, affecting technical, economic and social elements of society. Thus, it is important to study not only the technical innovations that are required for such a massive implementation of biomass, but also the conditions – that is, production and consumption processes, markets, policy and other social structures – existing before the implementation of these innovations, as it is these conditions which will to a large extent determine how the innovations will be implemented and what reactions might be expected by producers, researchers, consumers, markets and NGOs. Although similarities can be found between different countries

where such innovations are implemented, the way the transition process develops in a given country at a specific time will be largely steered by the initial conditions. If one wants to assess what impact these innovations will have, and to determine how this transition can be steered in such a way that it leads to a biobased economy that is technically feasible, economically viable and socially desirable, it is crucial to understand the role of producers and consumers, of markets and NGOs, and of public debate and the way it influences policy.

The structure of this book is as follows. Starting with an analysis of transition processes and sustainability issues, we discuss principles of plant production and factors determining biomass availability. Next, state-of-the-art overviews are presented of processes where biomass can replace fossil fuels, including production of biofuels, biogas, polymers and biochemicals. In a separate section, we study the way markets and policies determine how innovative techniques will be set to work in the real world. This is further demonstrated in four country studies.

Taking such an integrated analytical perspective is not only desirable if we want to assess the potential impact of a biobased transition, but it is also a necessity. If we want to determine how to arrive at a biobased economy that is feasible, efficient and acceptable, we need to consider all elements of sustainable development.