CHAPTER 1

Introduction: Tackling Uncertainty in the Biobased Economy Through Science

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1.1 Introduction

Europe is confronted by the depletion of natural resources due to, among other issues, their unsustainable use, increased global competitiveness, the global population growth rate, and other challenging environmental and economic issues.[1] Promoting the sustainable growth of dynamic bioeconomy sectors will contribute to the transition from a fossil fuel-based society to an innovative, resource-efficient and competitive one. Biobased products represent a great opportunity to reconcile sustainable long-term growth with environmental protection through the wise and forethoughtful use of renewable resources for industrial purposes. However, managing those resources in a sustainable manner implies the addressing of major social, economic and environmental challenges and facing the potential risks associated with direct and indirect land use change as well as competition with the food industry.[2] Bearing this in mind, to steer the transition process along the desired sustainable pathway, specific policy and strategies should be designed to define a supportive regulatory structure.[3]

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To this aim, several sectoral policies and strategies have been developed in order to support the establishment of a comprehensive and effective policy framework for a biobased economy in Europe. In this sense, we can recall: the *Common Agricultural Policy*; the *2013 EU Forest Strategy*; the *Common Fisheries Policy*; the *Blue Growth Agenda*; and the *European Innovation Partnership for Agriculture*. Along with sectoral policies, the European Union has also adopted a series of horizontal policies affecting different value chains of the bioeconomy and supporting the transition toward a resource-efficient and low carbon economy. To this end, the following can be mentioned: the *Europe 2020 strategy*; the *Lisbon Agenda*; *European Circular Economy Package*; the *COP21 Paris Agreement*; the *2030 Climate and Energy Policy*; the *Lead Market Initiative*; the *European Bioeconomy Strategy and Action Plan*; the *Innovation Europe Flagship Initiative*.

In addition to strategies and policies, regulatory tools like standards and certification schemes can further support the establishment of a sustainable bioeconomy. Standards and certifications play a central role in promoting innovation activities by reducing perceived uncertainty and prompting the market uptake of new products. The role of standards is especially relevant in markets characterised by a high degree of uncertainty – such as the biobased market – stemming from the technological domain as well as social and environmental realms.[4]

In this respect, the development of comprehensive sustainability schemes and assessment tools for biobased products represents a first fundamental step towards the design of such standards and certification schemes, contributing to a clear and evidence-based view of environmental, economic and social impacts of biobased products and assisting policy makers in shaping their policy agenda. In this regard, the identification of new and effective ways of bridging the gap between scientists and policy makers is crucial to encourage the development, implementation and an effective management of the evidence-informed regulatory frameworks,[5] reducing in turn the uncertainty associated with the development of a radically new economic model.

Bearing this in mind, this book presents research results obtained within the Horizon 2020 project STAR-ProBio, aimed at promoting the development of sustainability schemes (including standards, labels and certifications) for the assessment of biobased products, which are considered fundamental to the establishment of a cutting-edge sustainable bioeconomy. The book is a collection of six chapters (plus an introductory and a concluding chapter), which cover a range of issues spanning from upstream and downstream environmental assessment, techno-economic assessment, social assessment, to cross-cutting issues such as indirect land use change (iLUC) and end-of-life options.

In this introductory chapter we propose an overarching framework of analysis to grasp the impact that sustainability schemes and sustainability assessment tools can play in reducing uncertainty and promoting the transition towards a bioeconomy – making sense of the research conducted in the following six chapters as pieces of a complex puzzle which need to be considered unitarily in order to achieve the desired goal.

The remainder of this introduction is organised as follows: a theoretical discussion, reviewing the concept of uncertainty associated with the bioeconomy, is provided in Section 1.2; in Section 1.3, the proposed uncertainty map is offered to the reader as a red thread linking the six main chapters composing the book; Section 1.4 presents concluding remarks.

1.2 Proposed Framework of Analysis: Science–Policy and Science–Market Bridges for Reducing Uncertainty

Uncertainty is a major challenge for new economic activities as well as for already established businesses aiming to explore new opportunities. In the presence of a high degree of uncertainty, entrepreneurs might be reluctant from investing financial resources while policy makers could be discouraged from promoting a transition whose societal and environmental impacts are not clear. Hence, it is no surprise that economists have repeatedly attempted to tackle the issue of uncertainty in transition processes.

Building on the traditional definition first proposed by Frank Knight,[6] uncertainty can be understood as risk that is not possible to calculate. In this sense, uncertainty differs from risk as the latter refers to a situation where the probability of the alternative outcomes (or alternative states of the world) is either known *ex ante* or can be reliably estimated. Conversely, uncertainty entails the impossibility of specifying numerical probabilities for specific events. Beyond uncertainty, more often than not, obtaining knowledge about all alternative outcomes is problematic. Under this condition, economists introduced two further notions – namely ambiguity and ignorance. Following Dosi and Egidi,[7] we shall refer to these four types of uncertainty (*i.e.* risk, uncertainty, ambiguity and ignorance) as substantive uncertainty. Another layer can be added when introducing procedural uncertainty – that uncertainty associated with the lack of cognitive competences needed to make the best possible use of the available information. In other words, under procedural uncertainty decision makers are constrained in their computational and cognitive capabilities. As argued in Morone and Tartiu,[8] complex innovation systems – such as the one involving a transition to a biobased economy – are largely characterised by both substantive and procedural forms of uncertainty.

For the sake of clarity, in the context of a transition to a biobased economy, we shall reduce these areas of uncertainty to two domains of analysis. Uncertainty associated with a new biobased socio-technological regime stems from unknown internal costs and benefits (*techno-economic uncertainty*) as much as from unknown external costs and benefits (*e.g. environmental and social uncertainty*). These two domains of uncertainty affect, in turn, the market structure and the policy action.

On the one hand, a high degree of techno-economic uncertainty might prevent investors from endowing the needed resources and putting innovative activities on hold. This undermines the market potential development of the new economic activity and might ultimately prevent the transition from occurring. High degree of environmental and social uncertainty, on the other hand, would pose a constraint to policy actions aiming at stimulating the transition – since investing taxpayers' money into a policy action whose social and environmental benefits are not fully proofed might turn to be a rather unpopular policy initiative.

1.2.1 Techno-economic Uncertainty

Following Maijer *et al.*,[9] and elaborating on their proposed framework, we shall maintain that techno-economic uncertainty stems from the following internal sources:

1. Technical uncertainty: this source of uncertainty stems directly from the lack of knowledge on the production process associated with the new technology. Typically, this refers to poor information available on the cost structure of the new technology, the availability of several concurring technological options (hence the lack of a technologically dominant design) and the stakeholders' perception of technology (based on their knowledge, previous experiences, expectations, risk aversion, *etc.*). Further, uncertainty about the relation between the technology and the infrastructure within which the new technology will be integrated is also relevant. Thus, this source of uncertainty may hinder a proper assessment of the innovation and consequently postpone the innovation decision or even encourage its abandonment.
2. Resource uncertainty: this source of uncertainty refers typically to the lack of financial and human resources. However, in the context of the biobased economy transition, the role of feedstock availability becomes extremely relevant. In this regard, interlinkages across different levels of the value chain become crucial involving, for instance, the cascading use of resources.
3. Functionality uncertainty: this source of uncertainty is associated with products characteristics. The biobased economy is not only about producing the same products in different ways, but mostly producing new products in different ways and using different inputs. This implies a growing uncertainty related to products functionality associated with, among other things, the quality of feedstocks, the reliability of production processes, the chemical and mechanical properties of new materials, consumers' acceptance of new product designs, *etc.*

These three sources of uncertainty involve two typologies of actors: producers and consumers and propagate into the locus of their interaction – *i.e.* the market. Hence, techno-economic uncertainty impacts on market uncertainty.

1.2.2 Environmental and Social Uncertainty

External sources of uncertainty refer to the lack of knowledge on the impact that the new socio-technological regime will have on social welfare through environmental and social externalities. In this sense, environmental and social uncertainty stems from the following external sources:

1. Environmental uncertainty: this source of uncertainty relates to the lack of knowledge on the overall impact of the new process or product on the environment. Albeit the transition out of a fossil-based economy into a biobased one is undertaken with the specific aim of reducing the impact on the environment, the superiority in terms of environmental sustainability of biobased products with respect to conventional ones is not straightforward and has to be rigorously proved. This relates to the high complexity associated with the new biobased regime, which involves a plethora of variables and the associated web of causal relations (often involving complex feedback effects, revers causality and simultaneity) on a global scale. Moreover, the environmental impact should be always assessed looking at both upstream (*i.e.* the use of alternative feedstocks and processes) and downstream (*i.e.* end biobased products and their fossil-based commercial equivalents) stages of the value chain taking into consideration alternative end-of-life routes.
2. Social uncertainty: this source of uncertainty relates to the lack of knowledge on the impact that the new biobased regime has on societal challenges including, among others: green jobs creation, labour conditions, rural area development, social inclusion and food security. Again, uncertainty stems from the complexity of the system and the multitude of variables involved. As an exemplification, the unforeseen food crops *vs.* energy crops debate has cast a shadow on the biofuel sector among researchers, analysts and policy makers as well as the general public.
3. Health uncertainty: this source of uncertainty has two dimensions. On the one hand, it relates to the impact that the new biobased production system has on workers operating in possibly contaminated environments (*e.g.* those operating on waste valorisation plants or dealing with potentially toxic chemicals); on the other hand, it relates to the impact that consumables, produced for instance with secondary raw materials, might have on consumers health (*e.g.* food packaging, cutlery, diapers, cosmetics, *etc.*).

These three sources of uncertainty involve two typologies of actors: policy makers and consumers and propagate into the policy domain where they interact in the form of principal and agent. Hence, environmental and social uncertainty impacts on policy uncertainty as it poses a hurdle to the deployment of proactive policies in support of the transition.

1.2.3 Mapping and Bridging Uncertainty in the Biobased Economy

Building on the framework developed above, Table 1.1 summarises domains, sources and actors associated with uncertainty in the biobased economy. This mapping exercise allowed us identifying four domains within which uncertainty arises. Our next step will aim at establishing cross-links among these domains and defining possible bridges to curb uncertainty.

As discussed above, techno-economic uncertainty impacts upon market uncertainty. Hence, reducing techno-economic uncertainty might, in turn, impact positively upon market uncertainty. Specifically, performing a scientifically sound assessment of production costs and revenues (associated with alternative production functions as well as alternative feedstock) would allow producers to be more confident in the real chances of being competitive in the emerging market, and to assess their chances of success in the medium and long run. Moreover, this would affect consumers who are interested in products functionality and price and would perceive price signals as indicators of market stability.

This suggests that, developing scientifically robust methodologies, considering the whole life cycle of new products as well as the entire value chain, will allow curbing market uncertainty and, eventually, stimulate the market uptake of new biobased products.

Similarly, environmental and social uncertainty can be addressed by means of analytically rigorous environmental and social impact assessment. This involves processes to identify, predict and evaluate the impacts of new products and processes upon the environment (including all possible sources of positive and negative externalities) and key social indicators. In turn, a rigorous assessment of such impacts might prove to be a rather powerful tool to support science-based policy decision and, therefore, reduce policy uncertainty.

As it seems, the first two domains of uncertainty produce effects in terms of uncertainty related to the market stability and its potential size (the need to set new and complex value chains, which require long-term perspectives), as well as the uncertainty associated with the overarching policy framework.

Table 1.1 Domains, sources and actors associated with uncertainty in the biobased economy.

Domains of analysis	Sources of uncertainty	Involved actors	Domains of impact
Techno-economic uncertainty	Technical uncertainty Resource uncertainty Functionality uncertainty	Producers and consumers	*Market uncertainty*
Environmental and social uncertainty	Environmental uncertainty Social uncertainty Health uncertainty	Policy makers and consumers/citizens	*Policy uncertainty*

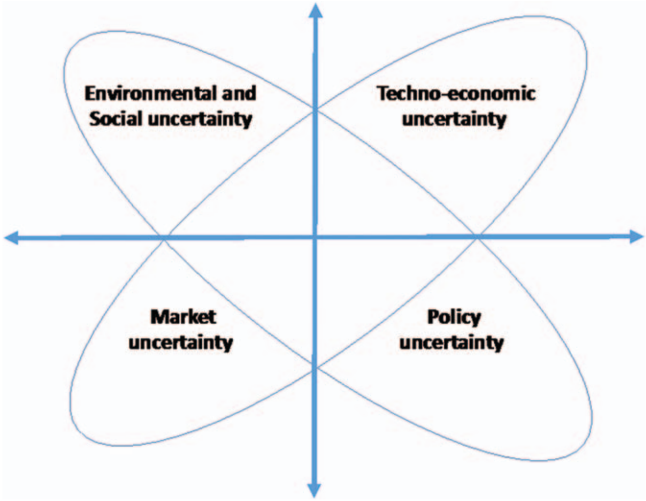

Figure 1.1 Uncertainty map.

Figure 1.1 summarises these links and the proposed establishment of science-policy and science-market bridges as a way of reducing uncertainty and promoting the transition to a biobased economy.

Market and policy domains are characterised by the existence of self-reinforcing links. Indeed, stable and harmonised policies would accelerate the market uptake of biobased products. In turn, a fast-growing market could trigger the policy interest and stimulate the adoption of supportive actions. By the same coin, this virtuous circle could revert into a vicious one, impeding the transition.

1.3 Uncertainty Map and Book Structure

Building on the conceptual framework developed in Section 1.2, we shall now look into the specific content of this book, assessing the contribution of each chapter in reducing market and policy uncertainty acting through the environmental and social domain and the techno-economic domain.

Moving from the assumption that biobased products' sustainability needs to be proofed, the chapters of this book provide a scientifically-based harmonised approach for environmental, social and economic sustainability assessments. This serves the purpose of reducing *techno-economic uncertainty* by assessing internal costs and benefits occurring through the whole value chains associated with new biobased products, as well as reducing *environmental and social uncertainty* by assessing external costs and benefits associated with the introduction of such new products in the market. In turn, this leads to the reduction of market and policy uncertainty by the definition of specific tools able to bridge science-policy and science-market realms.

Chapters 2 and 3 deal with upstream and downstream environmental assessment. Specifically, Chapter 2 provides an overview regarding the upstream activities that constitute forest and agricultural biomass production systems and primary processing (previous to downstream activities), paying special attention to the determination of their environmental assessment. The analysis is focused on the assessment of alternative feedstocks potential on selected biobased products. Chapter 3 focuses on how selected key sustainability characteristics can be quantitatively and qualitatively captured through use of life cycle analysis (LCA) and novel non-LCA based methodologies, covering a biobased product from their "manufacturing" to "end-of life" phases.

Uncertainty domain of analysis: environmental and social uncertainty
Uncertainty domain of impact: policy uncertainty

Chapter 4 presents a techno-economic sustainability analysis methodology for resource efficiency and the utilisation of renewable feedstocks for the production of biobased products. This includes the conversion routes of renewable feedstock resources to biobased products and development of techno-economic sustainability analysis methodology encompassing bioeconomy and circular economy aspects. It includes the definition of alternative end-of-life routes for biobased products and development of the techno-economic sustainability analysis methodology for each major end-of-life route. Finally, it defines techno-economic sustainability indicators for biobased products from alternative feedstocks through their end-of-life procedures.

Uncertainty domain of analysis: techno-economic uncertainty
Uncertainty domain of impact: market uncertainty

Chapter 5 looks closely at market dynamics providing an overview of the results of a foresight activity aimed at identifying the demand for new sustainability criteria that are easily understood by different consumer groups (end consumers, businesses and public procurers) and relevant to their needs. In this regard, this chapter attempts to lays a bridge between market needs – exemplified by consumer demand for new sustainability criteria, and research trajectories in providing such criteria.

Uncertainty domain of analysis: techno-economic uncertainty and environmental and social uncertainty
Uncertainty domain of impact: market uncertainty

Chapter 6 provides an overview of a Social Life Cycle Assessment (S-LCA) tailored to biobased products. As the authors maintain, despite being an emerging methodology, it offers a way to assess a product's socio-economic impacts, including human health related aspects, throughout the value chain, which represents a key issue in the specific case of biobased products.

It also provides key indications to policy makers concerned with the social impacts of a complex and pervasive transition out of a fossil-based society.

Uncertainty domain of analysis: environmental and social uncertainty
Uncertainty domain of impact: policy uncertainty

Chapter 7 provides insights on those mechanisms which may lead to undesired land use changes associated to the expansion of biobased products and which may result in adverse environmental and social impacts. Main findings in the literature are summarised and differences of biofuel *vs.* biobased products cases are shown in this chapter. It also shows how production routes can be associated to specific factors whose values proved sensitive to the land market and to subsequent land conversions. A novel risk approach to anticipate and counteract adverse effects is illustrated.

Uncertainty domain of analysis: environmental and social uncertainty
Uncertainty domain of impact: policy uncertainty

1.4 Conclusions

In this introductory chapter we propose a framework of analysis to grasp the impact that sustainability schemes and sustainability assessment tools can play in reducing uncertainty and promoting the transition towards a biobased economy. The six main chapters composing this book will provide scientific insights on how such schemes can be developed in a way that sustainability is assessed along the whole supply chain and in a circular perspective.

Moving from the assumption that a biobased economy is not a sustainable one by definition, this book will provide the reader with a comprehensive, albeit preliminary, set of methodologies and scientifically sound tools for sustainability assessment, paving the way to evidence-informed policy actions.

We suggest a framework of analysis where uncertainty is associated with two domains (the techno-economic domain and the environmental and social domain), which impact respectively on market uncertainty and policy uncertainty. The uncertainty mapping exercise served the purpose of providing an overarching umbrella where solutions to promote the transition towards a biobased economy can be identified in a way that bridges environmental and social sustainability as well as techno-economic sustainability with market-related issues and policy interventions.

The ongoing work undertaken as part of the STAR-ProBio project has, ultimately, the ambitious objective of developing two appropriate tools as viable ways of reducing market and policy uncertainty acting through the environmental and social domain and the techno-economic domain. Specifically, the research presented in this book is preparatory to the development of a fit-for-purpose sustainability assessment blueprint (the *SAT-ProBio*), which comprises a thoroughly selected list of indicators, both qualitative and quantitative, to assess biobased products' sustainability. The selection of such indicators is based on the complementary methodologies presented in the six chapters composing this book. The SAT-ProBio also serves the purpose of allowing comparisons between conventional and biobased counterparts. In this way, the blueprint becomes a valuable tool for supporting evidence-informed policy interventions and for creating a level playing field.

Once identified, the effectiveness of such policy intervention(s) can be evaluated against other policy actions aimed at boosting the transition to a circular biobased economy. To this aim, STAR-ProBio is also developing a user-friendly policy tool for assessing the impact of alternative policies (the *SyD-ProBio*). Specifically, a system dynamic model is being developed to assess different policy scenarios and provide policy recommendations for fostering the market development of biobased products. This serves the purpose of capturing the main drivers of the emerging biobased economy and providing support in fine-tuning policy interventions.

The SAT-ProBio and the SyD-ProBio are tightly linked to each other. Specifically, echoing the mentioned nexus between market and policy domains, the indicators selected to shape the SAT-ProBio feed into the SyD-ProBio structure (in the form of key variables). In turn, the SyD-ProBio provides a flexible tool to assess the impact of alternative policy scenarios upon market penetration of biobased products.

All in all, both tools provide an attempt to overcome uncertainty by means of scientifically sound approaches. At the same time, the 'user-friendly' nature of such tools allows creating an interface between science and policy making as well as between science and market operators including all relevant stakeholders (*e.g.* producers, consumer associations, trade associations, *etc.*).

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