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Tackling Uncertainty in the Bio-Based Economy Through Science
The case of the H2020 project STAR-ProBio

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1. Introduction

Europe is confronted by depletion of natural resources due to, among others, their unsustainable use, increased global competitiveness, population's growth rate, and other challenging environmental and economic issues (e.g. Morone, 2016). 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. Bio-based products represent a great opportunity to reconcile sustainable long-term growth with environmental protection through the wise/ forethoughtful use of renewable resources for industrial purposes. However, managing those resources in a sustainable manner implies addressing major social, economic and environmental challenges and facing potential risks associated with direct and indirect land use change as well as competition with the food industry (Ladu and Blind, 2017). 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 (Ladu and Quitzow, 2017).

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 the bio-based 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*; 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, 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* and the *Innovation Europe Flagship Initiative*.

In addition to strategies and policies, regulatory tools like standards and certifications 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 - like the bio-based market – stemming from technological domain as well as social and environmental realms (Blind et al 2017).

In this respect, the development of comprehensive sustainability schemes and assessment tools for bio-based products represents a first fundamental step to the design of such standards and certification schemes – contributing to a clear and evidence-based view of environmental, economic and social impacts of bio-based 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 (e.g. Bultitude, Rodari and Weitkamp, 2012), reducing in turn the uncertainty associated with the development of a radically new economic model.

In this paper 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 bioeconomy. We test the proposed framework referring to a specific case study – i.e. the STAR-ProBio project, a Horizon 2020 project which supports the European Commission in the full implementation of the European Bioeconomy Strategy by developing sustainability assessment tools for bio-based products, which are tested on bio-based products with the highest actual market penetration and highest potential for the future markets.

The remainder of the paper is organized as follows: a theoretical discussion, reviewing the concept of uncertainty associated with the bioeconomy, is provided in Section 2; in Section 3, the uncertainty map proposed is analysed in association with the STAR-ProBio project – a case study aiming at showing the effectiveness of bridge science with market and policy as a way to reducing uncertainty; Section 4 presents concluding remarks.

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 continually attempted to tackle the issue of uncertainty in transition processes.

Building on the traditional definition first proposed by Frank Knight (1921), 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 (1991), 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 – i.e. 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 (2015), complex innovation systems – such as the one involving a transition to a bio-based economy – are largely characterized by both substantive and procedural forms of uncertainty.

For the sake of clarity, in the context of a transition to a bio-based economy, we shall reduce these areas of uncertainty to two domains of analysis. Uncertainty associated with a new bio-based socio-technological regime stems from unknown internal costs/benefits (*techno-economic uncertainty*) as much as from unknown external costs/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, 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.

2.1 Techno-economic uncertainty

Following Maijer et al. (2006), 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 lack of a technological dominant design) and the stakeholders' perception of technology (based on their knowledge, previous experiences, expectations, risk aversion, etc.).
Thus, this source of uncertainty may hinder a proper assessment of the innovation and consequently postpone the innovation decision or even encourage its abandonment. Further, uncertainty about the relation between the technology and the infrastructure within which the new technology will be integrated shall also be considered.

(2) Resource uncertainty: this source of uncertainty refers typically to the lack of financial and human resources. However, in the context of the bio-based economy transition , the role of feedstock availability becomes extremely relevant. Being the transition pervasive throughout the whole value chain, interlinkages across different levels become crucial – this involving, for instances, the cascading use of resources.

(3) Functionality uncertainty: this source of uncertainty associates with products characteristics. The bio-based 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, among other things, with: quality of feedstocks, reliability of production processes, chemical and mechanical properties of new materials, consumers acceptance of new products design, 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.

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/product on the environment. Albeit the transition out of a fossil-based economy into a bio-based one is undertaken with the specific aim of reducing the impact on the environment, the superiority in terms of environmental sustainability of bio-based 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 bio-based regime which involves, on a global scale, a plethora of variables and the associated web of causal relations (often involving complex feedback effects, revers causality and simultaneity).

(2) Social uncertainty: this source of uncertainty relates to the lack of knowledge on the impact that the new bio-based regime has on societal challenges including, among others: green jobs creation, rural areas 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 bio-based new 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/citizens 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.

2.3 Mapping and bridging uncertainty in the bio-based economy

Building on the framework developed above, Table 1 summarises domains, sources and actors associated with uncertainty in the bio-based 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 (Ladu and Wurster, 2019) and would perceive price signals as indicators of market stability.

This suggests that, developing scientifically robust methodologies, considering the whole lifecycle of new products as well as the entire value chain, will allow curbing market uncertainty and stimulate the market uptake of new bio-based products.

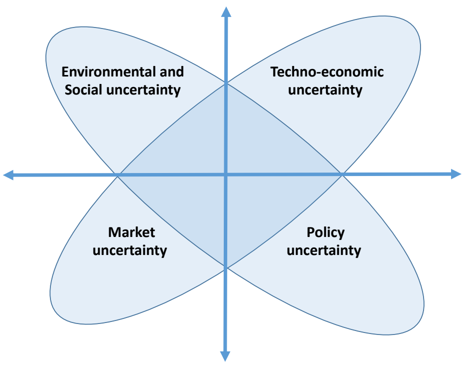
Table 1. Domains, sources and actors associated with uncertainty in the bio-based economy

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*

Similarly, environmental and social uncertainty can be addressed by means of analytically-rigorous environmental and social impact assessment. This involve processes to identify, predict and evaluate the impacts of new products/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 effect in terms of uncertainty related to the market stability and its potential size (the need to set new and complex value chains, which require a long-term perspective), as well as the uncertainty associated with the overarching policy framework. Figure 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 bio-based economy.
Market and policy domains are, by all means, characterised by the existence of self-reinforcing links. Indeed, stable and harmonised policies would accelerate the market uptake of bio-based 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.

Figure 1. Bridging over Uncertainty



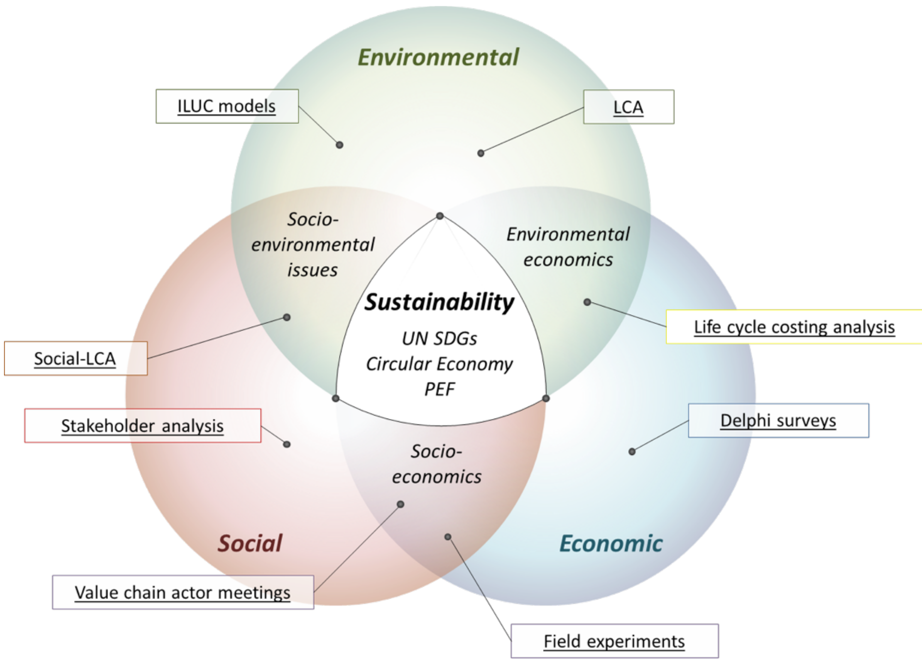
3. Case study

Building on the conceptual framework developed in section 2, we shall now look into a specific case study on the development of sustainability schemes for bio-based products, as a viable way of reducing market and policy uncertainty acting through the environmental and social domain and the techno-economic domain. Indeed, the lack of sustainability schemes for bio-based products represent a key market barrier (Majer et al. 2018); hence, the development of solutions for an effective sustainability assessment, plays a fundamental role in facilitating the market uptake of bio-based products and promoting evidence-informed policy actions.

Bearing this in mind, STAR-ProBio is performing a multidisciplinary study, promoting an efficient and stable policy regulation framework, needed to pave the way to the sustainability transition towards a bio-based economy and support the market uptake of bio-based products.

Moving from the assumption that bio-based products' sustainability needs to be proofed, STAR-ProBio defines 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 bio-based 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.
To reach these purposes, a consortium of 15 partners (involving universities, industries, SMEs and NGOs) is using a variety of methodologies (see Figure 2) in a complementary manner, integrating scientific and engineering approaches with social sciences and humanities-based approaches in order to address the four domains of uncertainty and support the establishment of the above-mentioned science-policy and science-market bridges.

Figure 2: The three pillars of sustainability annotated with the tools and methods used in STAR-ProBio



3.1. Assessing environmental and social uncertainty in STAR-ProBio

The environmental assessment is performed, through Life Cycle Assessment (LCA), in a circular economy framework (with a focus on end-of-life analysis and indirect land use change issues) looking at issues which emerge upstream and downstream the value chain. As part of this assessment, a set of hybridised indicators have been developed combining life cycle indicators with that of industrially-applied green chemistry resource efficiency metrics, also incorporating the principles of circular economy. The effectiveness of these methodologies was assessed against the LCA of bio-based PLA packaging films with respect to a fossil-based commercial equivalent from manufacturing to end of-life phases. In addition to the conventional LCA based impact indicators, the hybridised indicators including waste factor, secondary resource efficiency and circularity have also been applied. The methodologies provided a unique dimension to the sustainability evaluation of bio-based products, also highlighting some of the "easy to interpret" impacts, particularly waste generation, material and energy efficiency of the product and process in question (Lokesh et al., 2019).

This is complemented by a social assessment performed through stakeholder analysis, Social Life Cycle Assessment (S-LCA), surveys. Specifically, the main social impact categories and indicators that should be included in a social sustainability assessment of bio-based products have been identified following a threefold methodology. To identify which social categories and indicators are most relevant, a literature review on existing social life cycle studies was preliminary conducted; subsequently, focus groups with industrial experts and academics were implemented in order to corroborate, through participatory approach, information available in the literature. Afterwards, semi-structured interviews with consumers' representatives were conducted to further extend and validate findings. Core findings regards the effective inclusion of some social indicators (i.e., end users' health and safety, feedback mechanisms, transparency, and end-of-life responsibility) in the social life cycle assessment scheme for bio-based products. This would allow consumers, where properly communicated, to make more informed and aware purchasing choices, therefore having a flywheel effect on the market diffusion of a bio-based product (Falcone and Imbert, 2019).

3.2. Assessing techno-economic uncertainty in STAR-ProBio

The techno-economic assessment is conducted through Life Cycle Costing (LCC); moreover, specific attention has been dedicated to market assessment in order to contribute to the identification of major sustainability issues that need to be addressed to create the science-market bridge. This has been done by conducting an in-depth market analysis (mainly looking at the functionality of bio-based products) based on a three-round Delphi survey (implemented in selected Member States), and a field experiment, designed to elicit consumers' preferences towards bio-based products. The Delphi method was selected "to provide a generalized market-based view on acceptance factors for bio-based products. The first round collected the opinions of the participants on these factors in general and the second and third round are used to rank and refine the results". Two different target groups are addressed by the survey: professionals (public procurers, businesses, certification bodies and other institutions such as NGOs and researchers in the relevant field) and end-consumers (members of the public). While the survey targeted two different groups of stakeholders (professionals and end-consumers), the field experiment was designed to assess consumers' preferences by comparing their willingness to pay (WTP) for a conventional product against an identical bio-based product without an ecolabel and an identical bio-based product with an ecolabel.
The overall objective of the Delphi survey and the field experiment is to assess the market potential of bio-based products, hence reducing market and policy uncertainty through the adoption of scientifically-based interventions.

3.3. Two tools for bridging over uncertainty

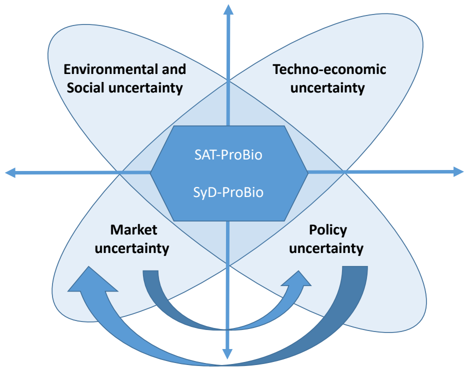
The described methodologies used to reduce environmental and social uncertainty as well as techno-economic uncertainty are merged into two specific tools used to "bridge over uncertainty" and supporting an evidence-informed policy-making (see Figure 3). Specifically, STAR-ProBio is developing a fit-for-purpose sustainability assessment blueprint (the SAT-ProBio), which comprises a thoroughly selected list of indicators, both qualitative and quantitative, to assess bio-based products' sustainability. The selection of such indicators is based on the use of the above-mentioned complementary methodologies. Selected indicators are classified distinguishing among those that are mandatory and those that are desirable. Moreover, to operationalise the blueprint, threshold values are identified whenever possible; such thresholds are understood as moving targets rather than fixed ones. In this way, bio-based products' sustainability is defined as a dynamic concept which can be improved over time and continuously updated.

The SAT-ProBio serves also the purpose of allowing comparisons between conventional and bio-based 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 bio-based economy. To this aim, STAR-ProBio is developing also 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 bio-based products. This serves the purpose of capturing the main drivers of the emerging bio-based 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 its turn, the SyD-ProBio provides a flexible tool to assess the impact of alternative policy scenarios upon market penetration of bio-based products.

Figure 3. STAR-ProBio approach to "Bridging over Uncertainty"



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.).

4. Conclusions

In this paper 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 bio-based economy. We test the proposed framework referring to a specific case study – i.e. the STAR-ProBio project, a Horizon 2020 project which supports the European Commission in the full implementation of the European Bioeconomy Strategy by developing two specific tools for: assessing bio-based products sustainability, and evaluating alternative policy scenarios. Indeed, a bio-based economy is not a sustainable one by definition. Its sustainability (and superiority with respect to fossil-based economy) has to be proved in a rigorous way, making use of robust methodologies and scientifically sound assessment tools. This will allow taking evidence-informed policy actions.

We suggest a framework of analysis where uncertainty is associated to two domains (techno-economic domain and environmental and social domain), which impact respectively on market uncertainty and policy uncertainty. For the two domains of uncertainty key sources and actors were listed. The uncertainty mapping exercise served the purpose of identifying scientifically-based solutions to promote the transition towards a bio-based economy by bridging research conducted to assess environmental and social sustainability as well as techno-economic sustainability with market-related issues and policy interventions.

Through the STAR-ProBio case study, we look at two tools (SAT-ProBio and SyD-ProBio) as viable ways of reducing market and policy uncertainty acting through the environmental and social domain and the techno-economic domain. Specifically, by developing these tools, the H2020 project STAR-ProBio is contributing to the establishment of a cutting-edge sustainable circular bio-based economy in Europe, bridging the gap between science and policy and between science and market. Indeed, the success of such a circular bio-based economy also relies on consumers acceptance and demand growth for bio-based products.

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