STAR-ProBio

Sustainability Transition Assessment and Research of Bio-based Products

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Deliverable D9.5
Report on policy effectiveness and alternative scenarios comparison

Version 1.0

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Abstract

Policies with relevance to products based on bio-based carbon are unquestionably key for the transition towards a sustainable circular European bioeconomy. The **STAR-ProBio** project dedicates the last deliverable of WP9 to highlight and simulate the European policy arena and respective scenes which are potentially relevant for the market development of progressively sustainable bio-based materials. The aim of this research is to provide tested recommendations for framework conditions and coherent policy portfolios for a level playing field towards increasingly sustainable production and consumption patterns. Therefore, the **SyD-ProBio model** is co-developed with various stakeholder groups in a "systems science based and stakeholder participatory group modelling" process. The system dynamics model developed by using STELLA® software is designed to serve as a decision support tool for a comprehensive understanding of key dynamics and conditions in the complex bio-based polymer sector from many different aspects (i.e. political, environmental, social, technological, legal, institutional and economic). A graphical user interface allows for explorative scenario simulations for discussions. Systems-modelling is complemented with an innovative clustering methodology on the basis of an extensive database of existing and upcoming relevant policy documents and individual policies. We find, that quantifiable policy options, that could be easily integrated into the **SyD-ProBio model** are rare in the European policy arena and focus on mainly on renewable energy provision, energy efficiency and especially the end of life sector. Furthermore, the working plan of the current Commission includes several frameworks open for debate in the months following the **STAR-ProBio** finalisation, where findings regarding standardisation and labelling will have to be positioned. Next steps should focus on further extension and testing of the model, as well as the development and analysis of strategies to cohere policies.

Suggested citation

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Disclaimer

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List of acronyms:

Acronym	Description
ALT	Alternative scenario
BAU	Business as usual scenario
BAT	Best Available Technology
BBI JU	Biobased Industries Joint Undertaking
BPA	Bisphenol A
CAP	Common Agricultural Policy
CLD	Causal loop diagram
CMF	Common Monitoring Framework
CO_2	Carbon dioxide
DRS	Deposit Refund Scheme
EC	European Commission
ECHA	European Chemicals Agency
EIB	European Investment Bank
EIP	European Innovation Partnership
EMAS	EU Eco-Management and Audit Scheme
EoL	End of Life
EPR	Extended Producer Responsibility
EU	European Union
EuCo	European Council
EUBP	European Bioplastics
FaST	Farmers sustainable nutrients tool
FaoStat	Statistical services of the International Food and Agricultural Organisation
FSC	Forest Stewardship Council
GAEC	Standards on good practices for agricultural and environmental condition of land
GPP	Green public procurement
GUI	Graphical User Interface
GWP	Global Warming Potential
IfBB	Institut für Biokunststoffe und Bioverbundwerkstoffe
MLP	Multi-level perspective
MS	European Member States
NGO	Non-governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PBS	Polybutylene succinate
PEFC	Programme for the Endorsement of Forest Certification
PENRR	Primary Energy from Non-Renewable Resources
PHA	Polyhydroxyalkanoates
PLA	Polylactic acid
PP	Polypropylene
PVC	Polyvinyl chloride
REACH	Regulation on European Chemicals
SAPM	Survey on Agricultural Production Methods
SME	Small and medium enterprise
SyD-ProBio	Systemic Dynamic model of the STAR-ProBio project
TEG	Technical Expert Group on
TFEU	Treaty on the Functioning of the European Union
UN	United Nations Sustainable Finance
UNCCC	United Nations Chapter on Climate Change

1. INTRODUCTION

1.1 Transition to bioeconomy – Importance of policy arena and the need for systems thinking approach

A transition to bioeconomy ensures not only a shift from the usage of finite non-renewable resources to renewable biomass-based feedstock, but also a reduction in the total CO_2 footprint and its contribution to global warming (EC, 2011). While addressing these key environmental challenges, a society based on bioeconomy has also tremendous potentials for economic growth and substantial public benefits (EC, 2011). As many national bioeconomy strategies around the world suggest, it can reduce dependency on fossil based raw materials and diversify energy sources, provide healthier and longer lives, increase the multifunctionality and scope of the agricultural and forestry sectors, improve manufacturing processes to yield carbon-neutral products, and increase employment by stimulating the regional development (The White House, 2012; BioteCanada. 2009; BÖR, 2011; BÖR, 2012; FORMAS, 2012; The White House, 2012). Hence, the bioeconomy is considered to be one of the most promising economic developments for the near future.

There is already an increasing demand for biomass, not only as feedstock for fuel/energy production, but also as fiber, food and feed with the growing global population. In parallel to increasing demand for biomass, the number of bioeconomy related innovations in key sectors such as agriculture, forestry, chemicals, food and pharmaceutical industries have also increased, in terms of new products, processes and services. It is clear that this trend will continue, and biomass resources will be an important part of future economic systems as food and feed, renewable energy resources, and materials and fibers.

Without a proper systems analysis for sustainable long-term planning and governance, however, such a transition also has the potential to generate severe negative impacts on the environment and socio-economic systems. Conversion of ecologically fragile and valuable lands to agriculture to supply the increased demand for feedstock, possible CO_2 emissions from such conversions, depleted and contaminated water resources, loss of biodiversity, and decreased soil quality, etc. are among the other important issues (IAASTD, 2009).

Hence, a sustainable transformation to bioeconomy requires a systems level redesign of interrelated transitions in existing socio-economic, socio-ecological and socio-technical systems in such a way that it sustains, not reduces the life support capacity of the Earth (Beddoe, R., et al., 2009). A redesign like this requires sustainable production and supply of biomass for production of food and non-food products, new smart technologies, changes in consumption preferences, and perhaps most importantly new institutional arrangements and legal frameworks that can interlink independently addressed policies from a wide range of areas/sectors across the whole biomass value chain.

In this redesigning process, the policy arena for bio-based products is unquestionably one key component. A vast array of policy instruments may affect, directly or indirectly, the market uptake of bio-based products, as well as the key dynamics across value chains of bio-based industries and the incumbent industries. To date, the policy arena for bio-based products encompasses a wide range of policy areas at global, EU and national level, which yet result in a complex, fragmented, uncoherent policy framework of action. Difficulties around agreeing on new legal frameworks, and formulating new policies and governmental measures add more complexity to the current situation. Consequently, the development of radical policies necessary for a sustainable bioeconomy imply a strong need for cross sectoral collaboration and inter/trans-disciplinary research adopting systems thinking approach.

Against this background, Task 9.5 – Policy analysis for the creation of a level playing field – of STAR-ProBio project aims at developing a system dynamics model and a clear depiction of the current policy arena for the assessment of the effectiveness of policy actions, and the creation of a level playing field for the bio-based products against fossil-based products.

At the stage of writing this deliverable D9.5, the STAR-ProBio project has already developed and put forward a framework proposal for selected modern and sustainable bio-based products mainly focusing on the standardization and certification of environmental, social and economic sustainability claims. While these results develop and refine the current scientific understanding based on thoroughly assessed case studies, consequential impacts of their implementation on the market-pull and the market uptake of these bio-based products in an economy, striving for a save and just operating space under stable environmental conditions, are yet to be discussed.

1.2 Objectives and the scope of this document

The main objectives of this project deliverable are:

1. to develop and present a system dynamics model (SyD-ProBio), which can serve as a decision support tool for a comprehensive understanding of key dynamics and conditions in the complex bio-based polymer sector from many different aspects (i.e. political, environmental, social, technological, legal, institutional, economic);
2. in parallel to model development work, to analyze current and potentially relevant future policies for defining alternative explorative policy scenarios that can be tested by the SyD-ProBio model; and
3. to demonstrate the use of SyD-ProBio model by simulating selected explorative policy scenarios and assessing the model results.

Given the very complex and cross-cutting nature of the policy arena for bio-based products, both SyD-ProBio model and the policy scenarios analysis build on a multi-stakeholder perspective and are addressed to EU and Member States policy makers working in the improvement of the policy framework guiding the promotion of sustainable bio-based products, more specifically biopolymers, and among all, polylactic acid (PLA) as a case study. Within the STAR-ProBio project it is only possible to provide the foundation for this analysis based on a conceptual tool combination containing (1) the stakeholder co-developed SyD-ProBio model, (2) a graphical user interface for explorative scenario discussions and (3) a clustering methodology based on a European landscape database.

2. METHODOLOGY

The methodological framework as implemented in the development of SyD-ProBio model encompasses combined *systems science based and stakeholder participatory group modelling process* with *appreciative inquiry model steps* (Figure 1).

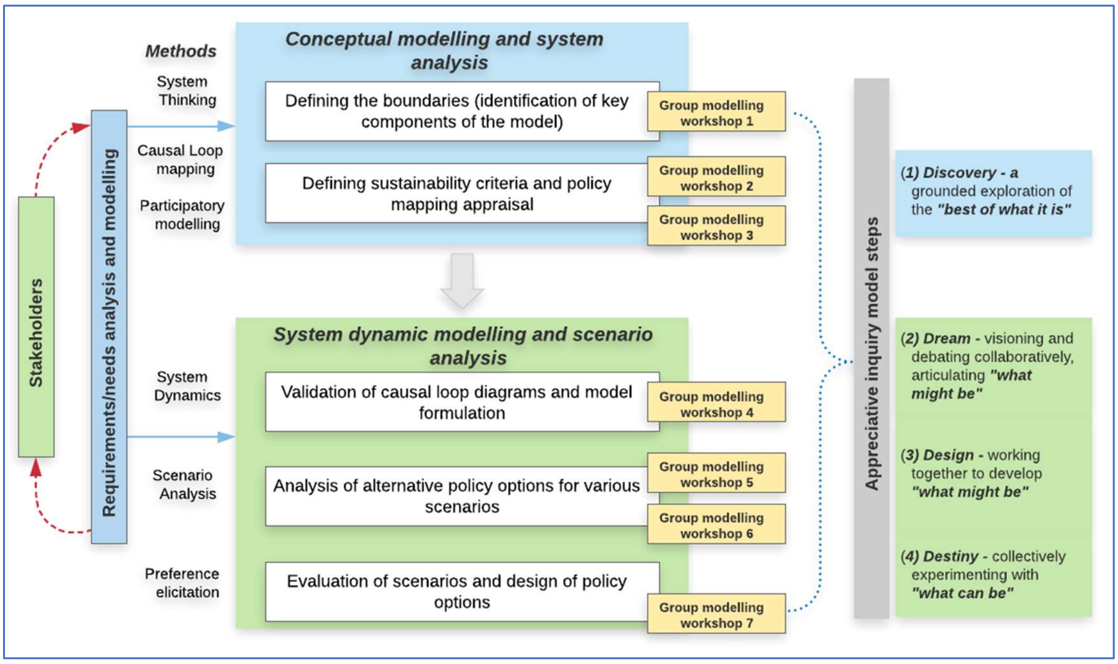

Figure 1: Methodological framework for the creation of the SyD-ProBio model. Source: own illustration

The *systems science based and participatory group modelling* was the core process in the development of the SyD-ProBio model. The process consists of two phases:

1. conceptual modelling and systems analysis; and
2. system dynamics modelling and integrated scenario analysis

Such a group modelling process has been proven to be effective for both conceptualization of a problem and guiding in the development of complex model simulations (Vennix et al. 1990, Richardsson 1994, Vennix et al. 1997, Haraldsson 2005, Haraldsson et al 2007, Hovmand et al. 2012, Hirschnitz-Garbers, M., et al. 2018, Sverdrup and Koca, 2018).

In our group modelling work, we merged the four steps of appreciative inquiry modelling (i.e. discover, dream, design and destiny) with the four steps of the group modelling learning method (Haraldsson 2005, Haraldsson et al. 2007; Haraldsson and Sverdrup 2020), including: (1) *Definition* – of structure and boundaries of the problem in time and space by asking the "right" questions. (2) *Clarification* – of conceptual models which are created and graphically illustrated to show causality and feedback loops between different factors that makes up the known and hidden structure of the problem. (3) *Confirmation* – and verification of the system structure, where there is a breakthrough of understanding of, what the "right" question is and what the key factors are driving the problem behaviour. There is a confirmation on the system boundaries, assumptions and limitations that enables sorting of type of measures that appropriate address the research questions. (4) *Implementation* – using the developed understanding to test understanding through appropriate tools. The true performance is evaluated, and experience gained used to further develop questions and research. Policy analysis is developed through this phase.

The core-advantages of such modelling process in fulfilling the Task 9.5 objectives are:

1. Given the complexity and cross-cutting nature of the policy arena for bio-based products, the system thinking approach helps to structure the available knowledge of the bioeconomy landscape, bringing together different individuals' understanding of parts of the system and creating a wider consensus of how these parts interact by means of causal loop diagrams;
2. the facilitation and exchange of the communication and knowledge among various groups of stakeholders - e.g. value chain actors, industry associations, policy makers, consumers, NGOs, modelling team, enhances the learning process about the system for which policy options are developed and tested. This is of particular importance given the difficulties around agreeing on new legal frameworks, on formulating new policies and governmental measures - adding to the complexity of the current bio-based products policy landscape;
3. The participatory group modelling process is a transparent and mutual learning process, in which participants have the chance to exchange experiences and knowledge in a series of workshops; in addition, it helps the modelling team to gather and document data about the system under investigation in a structured and unambiguous manner, as well as to identify gaps and inconsistencies in the data.

In accordance with the two phases of group modelling process, a series of small workshops with up to 12 participants have been conducted to elicit knowledge and preferences from relevant stakeholders involved in the bio-based realm, and thus fuel the development of the SyD-ProBio model. Specifically, in the conceptual modelling and system analysis phase we have organized three group modelling workshops aimed at (1) setting the SyD-ProBio model's boundaries (2) identifying key sector(s)/ bio-based products, and grasping a deeper understanding of their particularities (3) identifying and discussing intervention points for policy instruments for the selected sector(s)/bio-based product(s) and understanding how an "optimal" instruments mix for European bio-based products policy may look like.

In the three group modelling workshops we have involved stakeholders belonging to several categories - e.g. value chain actors, NGOs, industry associations, academia. The workshops have been organized within three months´ time-frame geographically close to the main involved stakeholders; November 14, 2018 in Rome (Italy), November 30, 2018 in Stockholm (Sweden) and January 11, 2019 in Berlin (Germany).

Furthermore, for the system dynamics modelling and integrated scenario analysis phase we have organized four group modelling workshops with the objectives of (1) refining and validating the causal loop diagrams emerged from the workshops conducted in the conceptual modelling phase, along with the development of SyD-ProBio sub-models (2) elaborating on the relevant policy instruments for the selected sector - bio-based plastics in Europe (3) exploring different bio-based transformation pathways (courses of actions) - e.g. phasing out fossil based polymers, promoting market uptake of bio-based polymers, supporting research and development for making bio-based polymers more compatible - functionally replacing the fossil based ones, making sure that bio-based polymers are sustainable and (4) identifying criteria for defining the policy mixes to be tested in the SyD-ProBio model while gathering data for the scenarios development. The four group modelling workshops have involved different stakeholders groups - e.g. value chain actors, NGOs, industry associations, academia, certification companies, policy makers - and have been held as follows; March 6-8, 2019 in

Lund (Sweden), April, 3rd,2019 in Santiago de Compostela (Spain), June, 13, 2019 in Rome (Italy) and February 11th, 2020 in Berlin (Germany).

The corresponding agendas and main outcomes from all of the organized workshops are presented in Annex 6.3 of this deliverable.

2.1 Conceptual modelling and systems analysis

Systems analysis deals with detailed examination of systems and the interactions of elements within and between such systems by creating conceptual model structures with the help of causal loop diagrams and ideally over a group modelling process (Vennix et al., 1990; Vennix 1997; Sterman, 2000). More specifically, systems analysis helps to identify a problem and build a conceptual model of a system at the root of the problem by clarifying the cause and effect relationships and the feedbacks between different elements of the system.

Causal loop diagramming methodology was developed by Forrester (1968) and further elaborated by Roberts et al. (1983) as part of the system dynamics modelling process. Kim (1992) provides a good description of causal loop diagrams (CLDs) as "[they] provide a language for articulating our understanding of the dynamic, interconnected nature of our world. We can think of them as sentences, which are constructed by linking together key variables and indicating the causal relationships between them. By stringing together several loops, we can create a coherent story about a particular problem or issue" (Kim 1992, p. 1). They are used to show the linkages between different elements/variables in a complex system and help us to understand the cause-effect relationships and feedback loops within that system (Richardson 1986, Haraldsson 2004).

Fel! Hittar inte referenskälla. depicts the diagramming conventions of a CLD. Specifically, the arrows that link each variable indicate places where a cause and effect relationship exists. The plus or minus sign in arrows indicates the direction of causality between the variables when all other variables conceptually remain constant. That is, the variable at the tail of each arrow causes a change in the variable at the head of each arrow in the same direction (in the case of a plus sign), or in the opposite direction (in the case of a minus sign). The overall polarity of a feedback loop - that is, whether the loop itself is positive or negative - in a causal loop diagram, is indicated by a symbol in its center. An "R" sign indicates a reinforcing loop (or equivalently known as positive feedback loop), and a "B" sign indicates a balancing loop (or negative feedback loop). In a reinforcing loop (R) the action of the loop is to influence the parameter in the same direction as it is already moving, whereas in a balancing loop (B) it is to return the parameter to its initial value (Sterman, 2000).

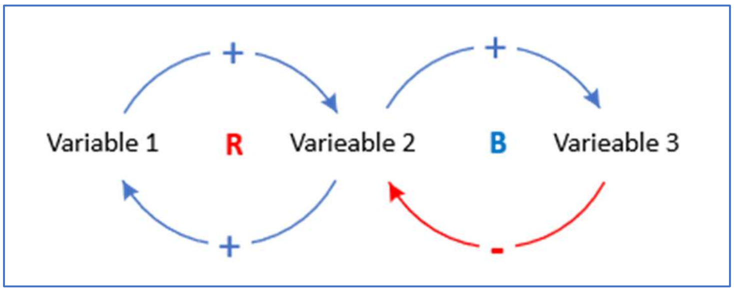

Figure 2: Conceptual illustration of a causal loop diagram. Source: own illustration

CLDs were used to facilitate the communication and knowledge exchange among the participants to the group modelling workshops. In an iterative process and throughout the documented workshops as well as based on further internal discussions, the various impact realms have been linked together.

In Figure 3 the overall result of this process is illustrated, depicting main drivers and barriers for the market introduction and market diffusion of bio-based polymers and bio-based products in general that aim at substituting fossil -based ones. It captures the dynamics of material flow of biomass (from agricultural land, to processors, bioplastics products and alternative end of life management options), the carbon stocks and CO2 emissions across the entire value chains of biopolymers and traditional oil-based polymers, as well as potential policies and incentives for increased used of biopolymers and market penetration. For example, starting with changing policy mixes boosting bio-based products development and market penetration, especially the utilization of biomass from various sources such as waste- and residues streams, from agri- and silviculture as well as from marine sources will be directly impacted. On the one hand, this could result in conflicts for the utilization of biomass for other purposes, on the other hand high standards could support more sustainable practices up to carbon binding measures. Use of fossil-based carbon for material utilization would be impacted negatively, however not without resulting in possible leakage effects.

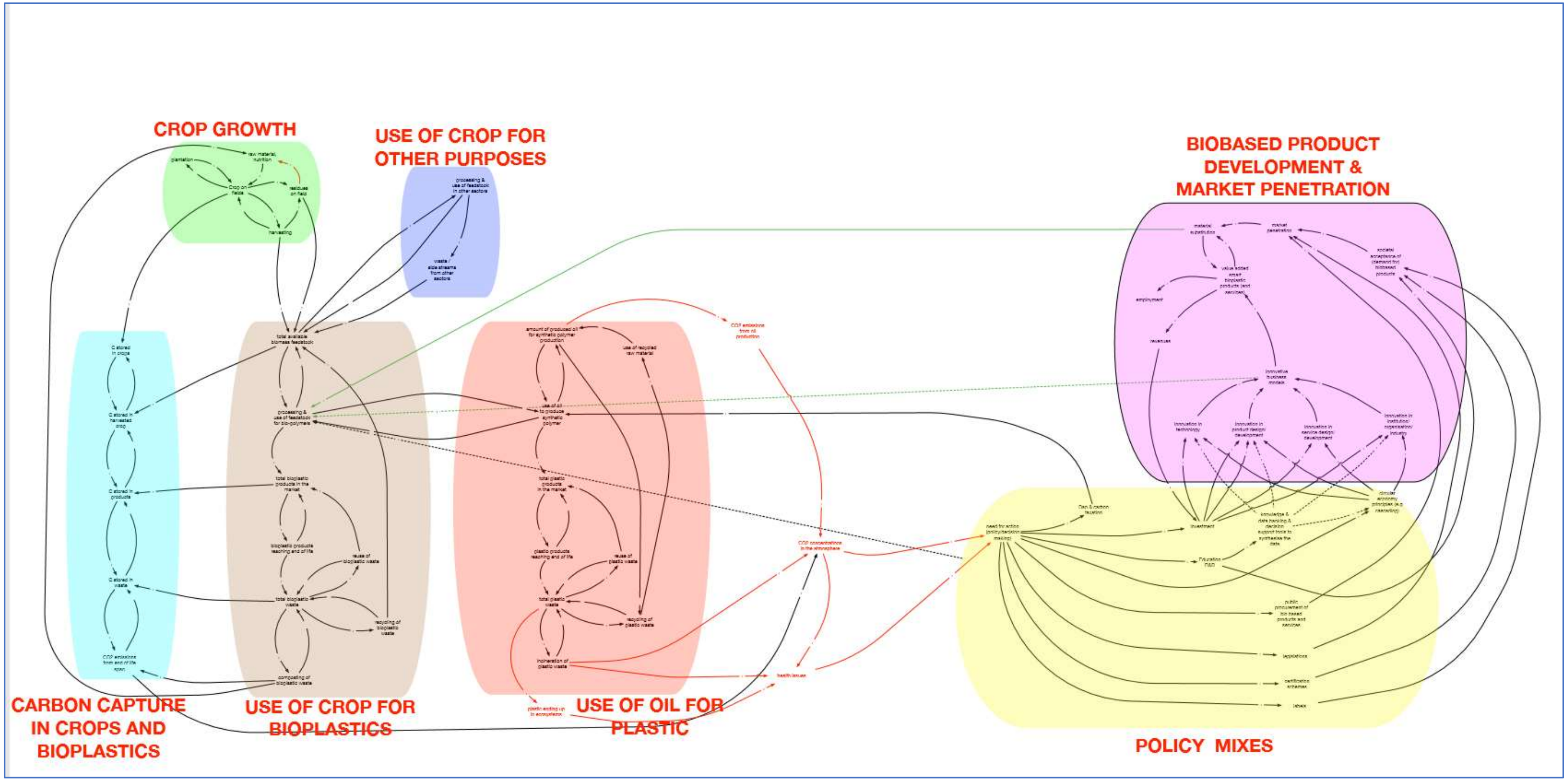

Figure 3: Conceptual modelling results including causal loop diagrams for the market uptake of bio-based polymers in Europe. A picture with a higher resolution can be found on the STAR-ProBio project Homepage. Source: own illustration

The *conceptual modelling and system analysis phase* has also been embedded in the Multi-Level Perspective (hereafter MLP) theoretical framework (see Figure 4) , taking into account that the shift from a fossil-fuel based regime to a bio-based regime is at the heart of the transition towards a sustainable bioeconomy for Europe, as indicated by several policy papers, strategies, action plans and roadmaps discussed later on in the presented deliverable D9.5.

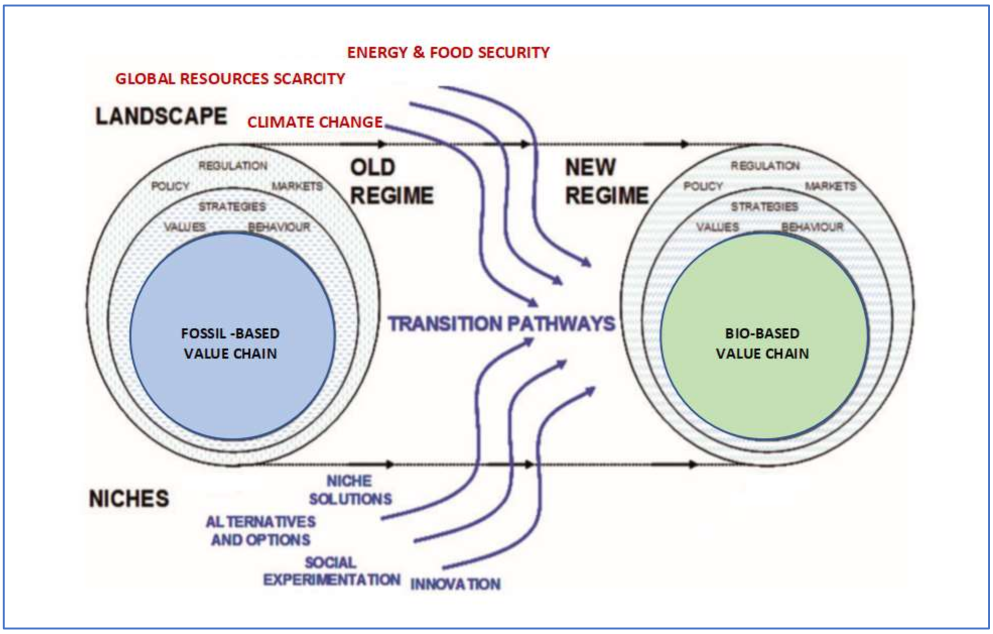

Figure 4: Multi-Level Perspective (MLP) framework. Source: own illustration adapted from (Chilvers et al., 2017)

The MLP is a heuristic framework, which covers three levels of analysis: the landscape (macro-level), the socio-technical regime (meso-level) and the niche (micro-level). Technological transitions can be explained through the interaction among these three levels as the transition basically entails a shift from an incumbent socio-technical regime to a new one, which is nurtured in the technological niche and prompted at the landscape level. Landscape and niches are derived concepts 'because they are defined in relation to the regime, namely as practices or technologies that deviate substantially from the existing regime, and as external environment that influences interactions between niche(s) and regime' (Geels, 2011). In this model, transition occurs whenever a pressure at landscape level destabilizes the regime, thus creating a window of opportunity for pioneering niche-innovations to enter in the mainstream market.

In the bio-based economy context the niches innovations could take various forms stretching from the development of new technologies to behavioral changes (e.g. new consumption models). This reflects the multivariate nature of the phenomenon under scrutiny, which involves changes occurring at various levels (social, economic, environmental, contextual) all concurring to complete the transition.

2.2 SyD-ProBio system dynamics model description

SyD-ProBio model is the final outcome of the system dynamics modelling work within Task 9.5 of the STAR-ProBio project. It is a system dynamics model developed by using STELLA® software by ISEE systems. It is intended to serve as a decision support tool for a comprehensive understanding of key dynamics and conditions in the complex bio-based polymer sector from many different aspects (i.e. political, environmental, social, technological, legal, institutional and economic).

Due to the complex structure of the polymer sector (several different biopolymers, which can potentially substitute different oil-based polymers), in the current version of SyD-ProBio we limited our modelling work with a focus on market uptake of polylactic acid (PLA) by substituting polypropylene (PP). With its modular structure, however, it is relatively easy to extend and/or modify the model by implementing new modules or changing existing ones, based on the availability of input data and policy options to be tested.

This section presents the general structure of the current version of the SyD-ProBio model and provides a description of key modules, sub-modules and parameters used in the model. An overview of the PLA module is given in Figure 5: An overview of the SyD-ProBio model PLA module. Source: own illustration to illustrate the extent of the work in STELLA software.

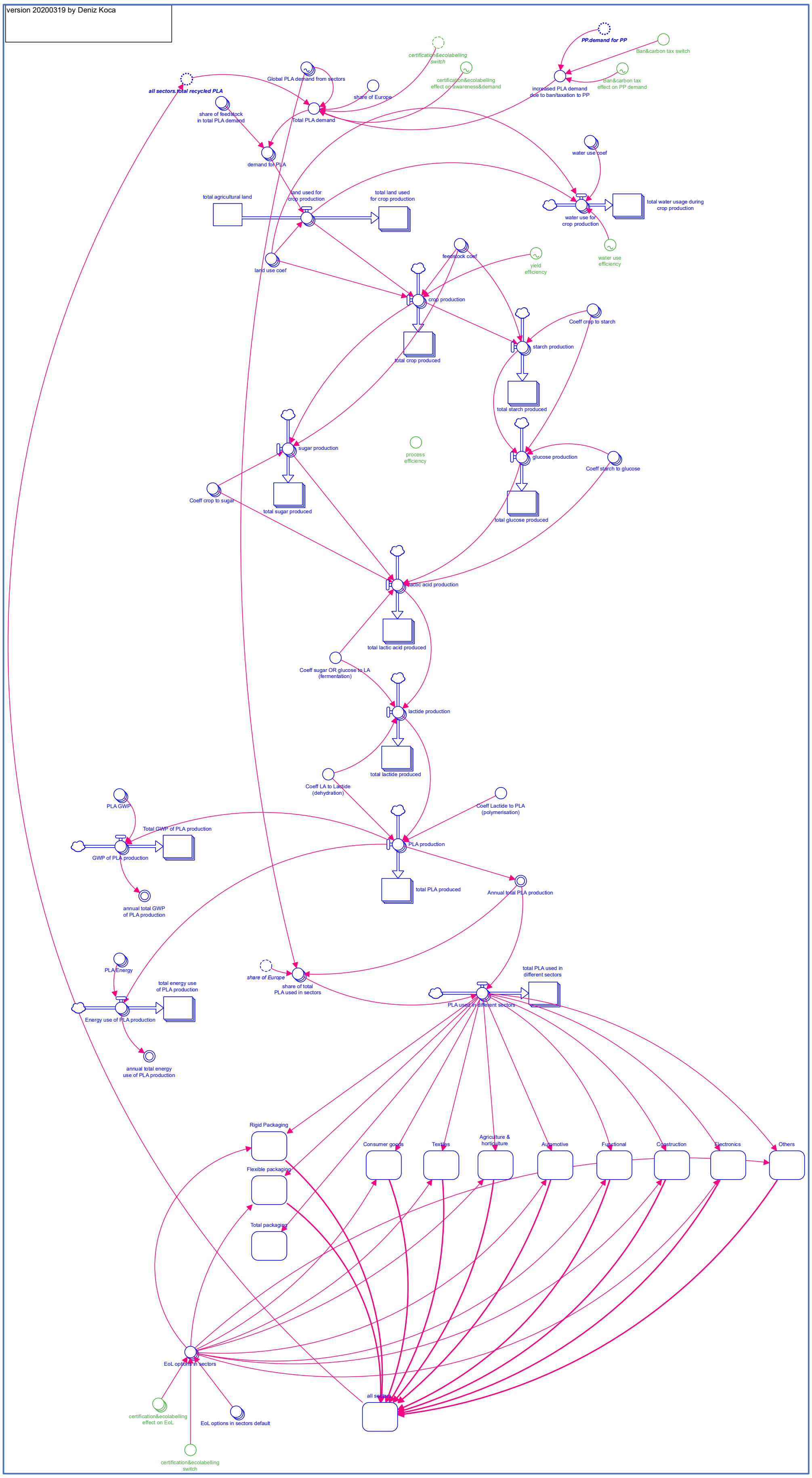

Figure 5: An overview of the SyD-ProBio model PLA module. Source: own illustration

In the following and based on more readable graphs, we describe the most important parts of the current version of the model in more detail. These parts correspond to:

- key stages of the PLA value chain: (1) the primary biomass production, (2) the biomass processing (for the case of PLA production process) and (3) the use and End of Life options (EoL) of PLA in sectors, (4) the global warming potential of PLA production and (5) primary energy from non-renewable resources for PLA production; as well as
- (6) PolyPropylene (PP) production, (7) global warming potential of PP production, and (8) primary energy from non-renewable resources for PP production.

2.2.1 Primary biomass production

Five different crop types are considered in the current state of the model for providing raw materials for PLA production in the SyD-ProBio model. These crop types are *sugar cane, sugar beet, corn, potato* and *wheat*.

The Syd-ProBio model calculates the land and water requirements for the production of different crop types, as well as the crop yield (Figure 6)

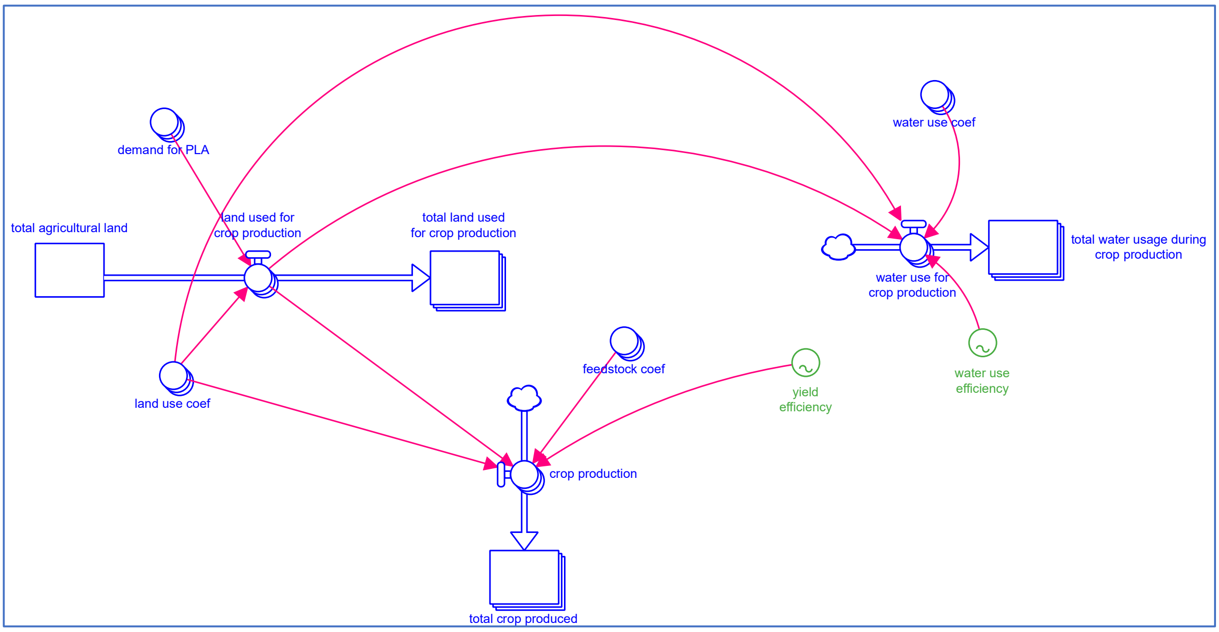

Figure 6: Primary biomass production in the SyD-ProBio model. Source: own illustration

Land Use:

Area of land $\left[{ha}/{year} \right]$ required to produce different types of crops for PLA production is calculated with an array function in the SyD-ProBio model with the formula:

*land_used_for_crop_production[Crop_type] = demand_for_PLA*land_use_coef*

where;

demand_for_PLA is the European PLA demand $\left[{t}/{year} \right]$ from various sectors. This parameter is estimated from European Bioplastics market data on global production capacities of bioplastics by market segment (observed and projected for the near future between 2017-2023) (EUBP, 2019).

land_use_coef is the area of land required to produce the necessary amount of crop, which can be processed into 1 tonne of PLA. The SyD-ProBio model considers different *land_use_coef* for each of the five crop types (Figure 7).

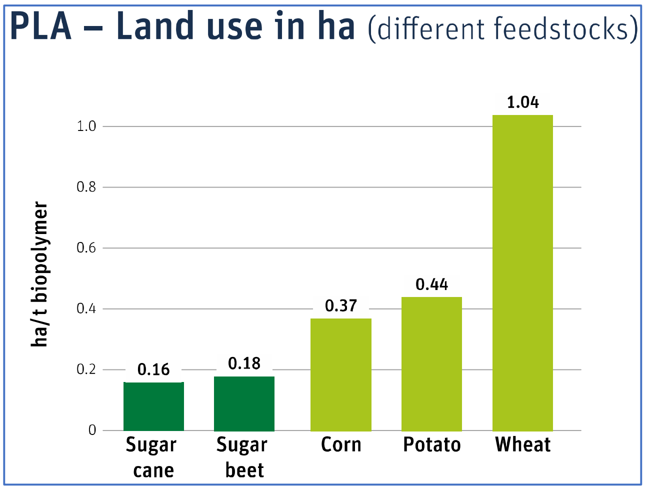

Figure 7: Land use for the production of different crop types, which can provide the necessary raw material to produce 1 tonne of PLA. Source: (IfBB, 2019)

Water Use:

The SyD-ProBio model calculates the volume of water $\left[m^3/year\right]$ to produce different types of crops for PLA production with a formula in an array function:

water_use_for_crop_production[Crop_type] = land_used_for_crop_production(water_use_coef*(1+water_use_efficiency))/land_use_coef*

where;

water_use_coef is the volume of water required to produce the necessary amount of crop, which can be processed into 1 tonne of PLA. The model considers different *water_use_coef* for each of the five different crop types (Figure 8).

water_use_efficiency is an efficiency parameter in percentage that can be changed by the model user in the model user interface anytime during the simulation.

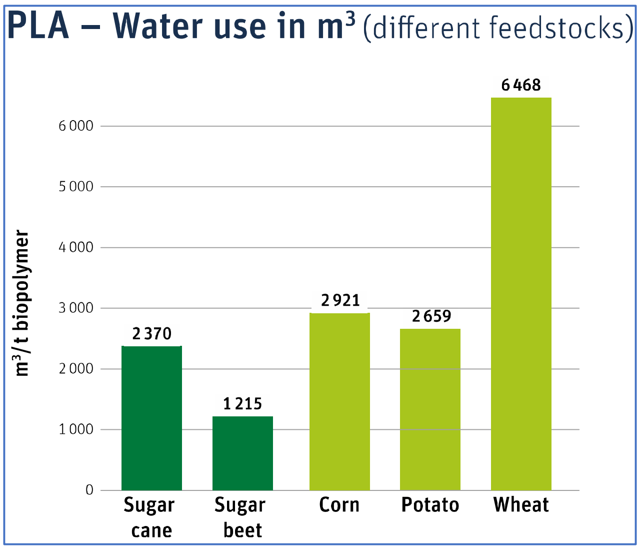

Figure 8: Water use for the production of different crop types, which can provide the necessary raw material to produce 1 tonne PLA. Source: (IfBB, 2019)

The water use data for each of the five different crop types are adopted from the study by (IfBB, 2019). The water use data is based on the information on water use for different raw materials collected by the "Water Footprint Network". It is based on Food and Agriculture Organization of UN – Statistics Division (FAOSTAT) crop definitions and it only considers the water use from "seed to market place", which accounts for the amount of water required to grow the whole plant. It includes rain water, irrigation water and to a certain extent processing water to clean the agricultural products.

Crop Yield:

Crop production (ton/year) which provides the feedstock to produce PLA is calculated with an array function in the SyD-ProBio model with the formula:

crop_production[Crop_type] = land_used_for_crop_production(yield_coef*(1+yield_efficiency))/land_use_coef*

where;

yield_coef is the amount of crop that can be processed into 1 tonne of PLA. The SyD-ProBio model considers different *yield_coef* for each of the five crop types. (Figure 9)

yield_efficiency is an efficiency parameter in percentage, which can be changed by the model user in the model user interface anytime during the simulation.

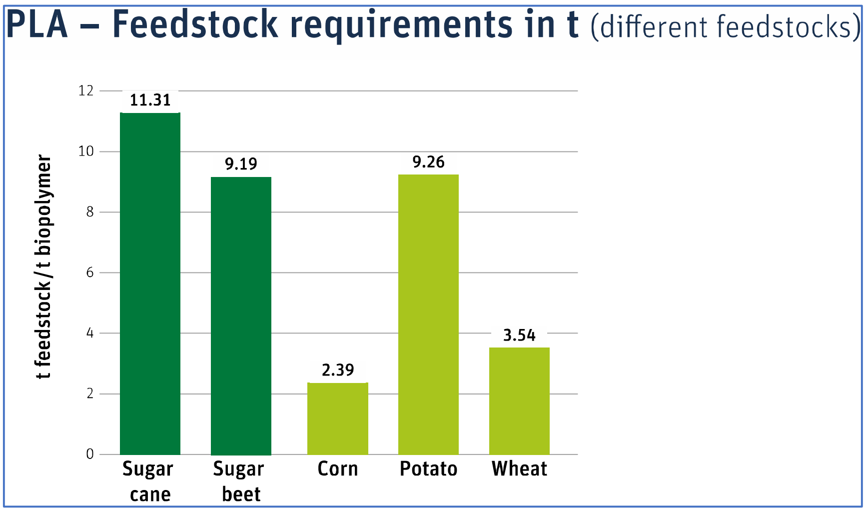

Figure 9: Amount of crop that can provide the necessary raw material to produce 1 tonne PLA. Source: (IfBB, 2019)

The yield data for each of the five different crop types are adopted from the study by (IfBB, 2019). The data calculations are based on the global mean yield over a period of 10 years (obtained from FAOSTAT, 2005 – 2014), weighted by respective production amount (Figure 10)

Feedstock	Crop	Raw material	Global mean yield * (Crop)
Calculations			-> x
Sugar cane	Sugar cane (without cane tops)	fermt. Sugar	72.7 t/ha
Sugar beet	Beet (without leaves)	fermt. Sugar	57.8 t/ha
Corn	Maize kernel	Starch	6.7 t/ha
Potatoes	Potato tuber	Starch	22.2 t/ha
Wheat	Wheat grains	Starch	3.74 t/ha

Figure 10: Amount of crop yield (global mean) per ha to produce PLA. Source: (IfBB, 2019)

2.2.2 Biomass processing – PLA production process

Following the primary biomass production calculations, SyD-ProBio model considers the processing of the biomass from different crops to PLA as end product (Figure 11).

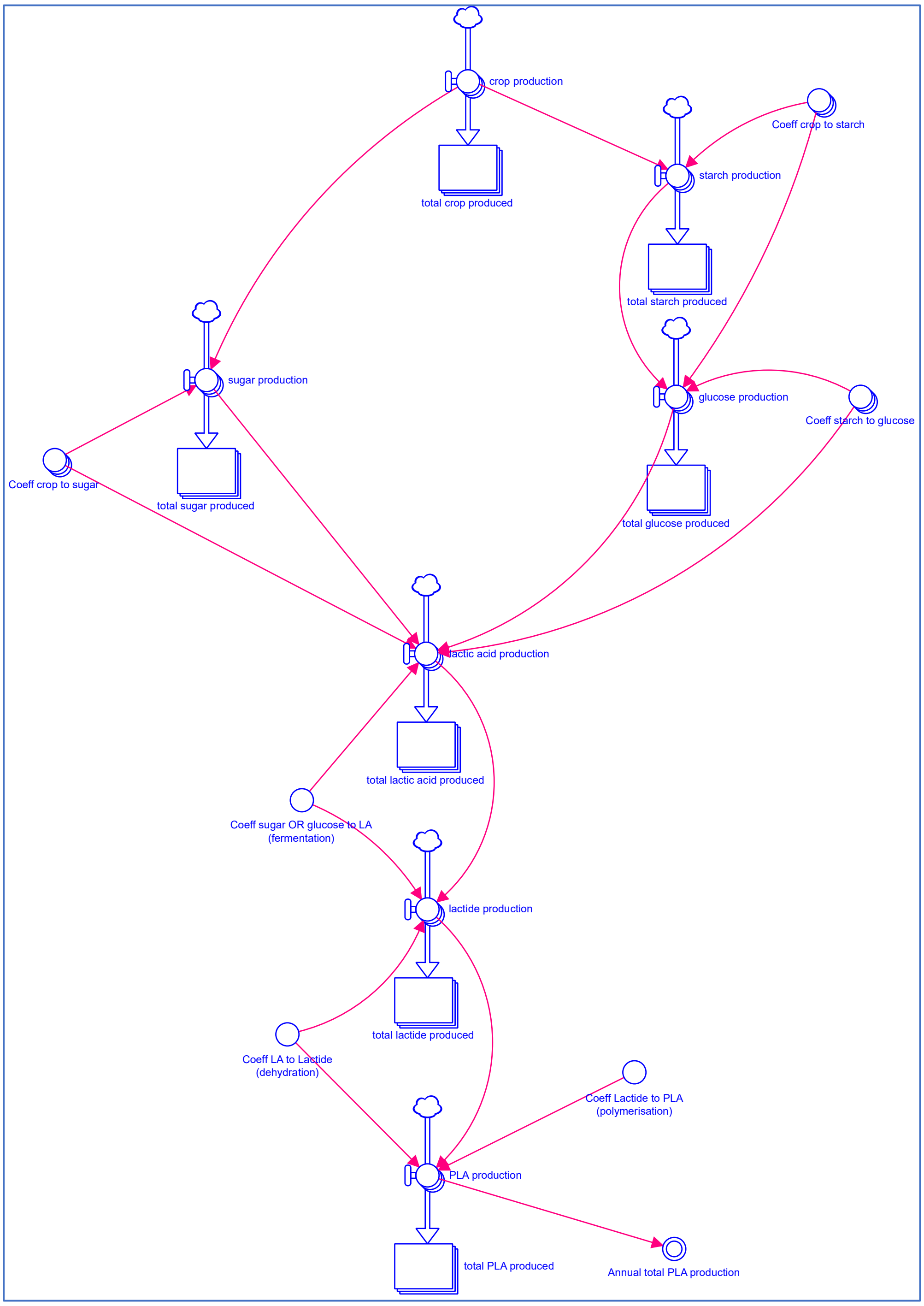

Figure 11: Biomass processing – PLA production process in SyD-ProBio. Source: own illustration

For the PLA production process in the SyD-ProBio model, we adopted the process route defined in the (IfBB, 2019).study. Mass flow calculations in this study are based on the chemical processes with known rates and conversion factors, which are also confirmed with polymer manufacturers and the industry. The calculations assume no losses along the process.

Starch production:

Starch production $[t/year]$, as raw material to produce PLA, is calculated with an array function in the SyD-ProBio model with the formula:

*starch_production[Crop_type] = crop_production*Coeff_crop_to_starch/yield_coef*

where:

Coeff_crop_to_starch is the amount of starch (ton) in the crop (only in corn, potato and wheat) as raw material to produce 1 tonne of PLA. A value of 1.67 is used based on the calculations provided in (IfBB, 2019). (Figure 12).

Feedstock	Crop	Raw material	Global mean yield * (Crop)	Average content of raw material	Resulting amount (raw material)
Calculations			->	x ->	=
Sugar cane	Sugar cane (without cane tops)	fermt. Sugar	72.7 t/ha	13 %	9.46 t sugar/ha
Sugar beet	Beet (without leaves)	fermt. Sugar	57.8 t/ha	16 %	9.24 t sugar/ha
Corn	Maize kernel	Starch	6.7 t/ha	70 %	4.69 t starch/ha
Potatoes	Potato tuber	Starch	22.2 t/ha	18 %	4.0 t starch/ha
Wheat	Wheat grains	Starch	3.74 t/ha	46 %	1.72 t starch/ha

Figure 12: Amount of crop yield (global mean) and resulting raw material per ha to produce PLA. Source: (IfBB, 2019).

Sugar production:

Sugar production $[t/year]$, as raw material to produce PLA, is calculated with an array function in the SyD-ProBio model with the formula:

*sugar_production[Crop_type] = crop_production*Coeff_crop_to_sugar/yield_coef*

where:

Coeff_crop_to_sugar is the amount of sugar $[t]$ in the crop (only in sugar cane and sugar beet) as raw material to produce 1 tonne of PLA. A value of 1.47 is used based on the calculations provided in (IfBB, 2019).

Glucose production:

Glucose production $[t/year]$, from starch with hydrolysis in the PLA production process, is calculated with an array function in the SyD-ProBio model with the formula:

*glucose_production[Crop_type] = starch_production*Coeff_starch_to_glucose/Coeff_crop_to_starch*

where:

Coeff_starch_to_glucose is the amount of glucose $[t]$ obtained from the starch to produce 1 tonne of PLA. A value of 1.47 is used in the processing route of corn, potato and wheat.

Lactic acid production:

Lactic acid production $[t/_{year}]$, from sugar and glucose with fermentation in the PLA production process, is calculated with an array function in the SyD-ProBio model with the formulas:

lactic_acid_production[Crop_type] = sugar_production"Coeff_sugar_OR_glucose_to_LA_(fermentation)"/Coeff_crop_to_sugar* (for sugar cane and sugar beet)

or

lactic_acid_production[Crop_type] = glucose_production"Coeff_sugar_OR_glucose_to_LA_(fermentation)"/Coeff_starch_to_glucose* (for corn, potato and wheat)

where:

Coeff_sugar_OR_glucose_to_LA_(fermentation) is the amount of lactic acid (ton) obtained from sugar or glucose to produce 1 tonne of PLA. A value of 1.25 is used in the calculations.

Lactide production:

Lactide production $[t/_{year}]$, from lactic acid with dehydration in the PLA production process, is calculated with an array function in the SyD-ProBio model with the formula:

lactide_production[Crop_type] = lactic_acid_production"Coeff_LA_to_Lactide_(dehydration)"/"Coeff_sugar_OR_glucose_to_LA_(fermentation)*

where:

Coeff_LA_to_Lactide_(dehydration) is the amount of lactide (tonne) obtained from the lactic acid to produce 1 tonne of PLA. A value of 1.0 is used in the SyD-ProBio model calculations.

PLA production:

PLA production (ton) from lactide with polymerisation in the PLA production process, is calculated with an array function in the SyD-ProBio model with the formula:

PLA_production[Crop_type] = lactide_production"Coeff_Lactide_to_PLA_(polymerisation)"/"Coeff_LA_to_Lactide_(dehydration)*

where:

Coeff_Lactide_to_PLA_(polymerisation) is the amount of PLA obtained from the lactide. A value of 1.0 is used in the SyD-ProBio model calculations.

Annual total PLA production:

Annual total PLA production is calculated by summing the yearly production amounts from five different crop types:

Annual_total_PLA_production = SUM(PLA_production)

2.2.3 Use and End of Life Options of PLA in sectors

In the SyD-ProBio model the total amount of PLA produced is used in ten different industrial sectors each presented with a separate module. These sectors are *rigid packaging, flexible packaging, consumer goods, textile, agriculture & horticulture, automotive, functional, construction, electronics* and *other* (Figure 13).

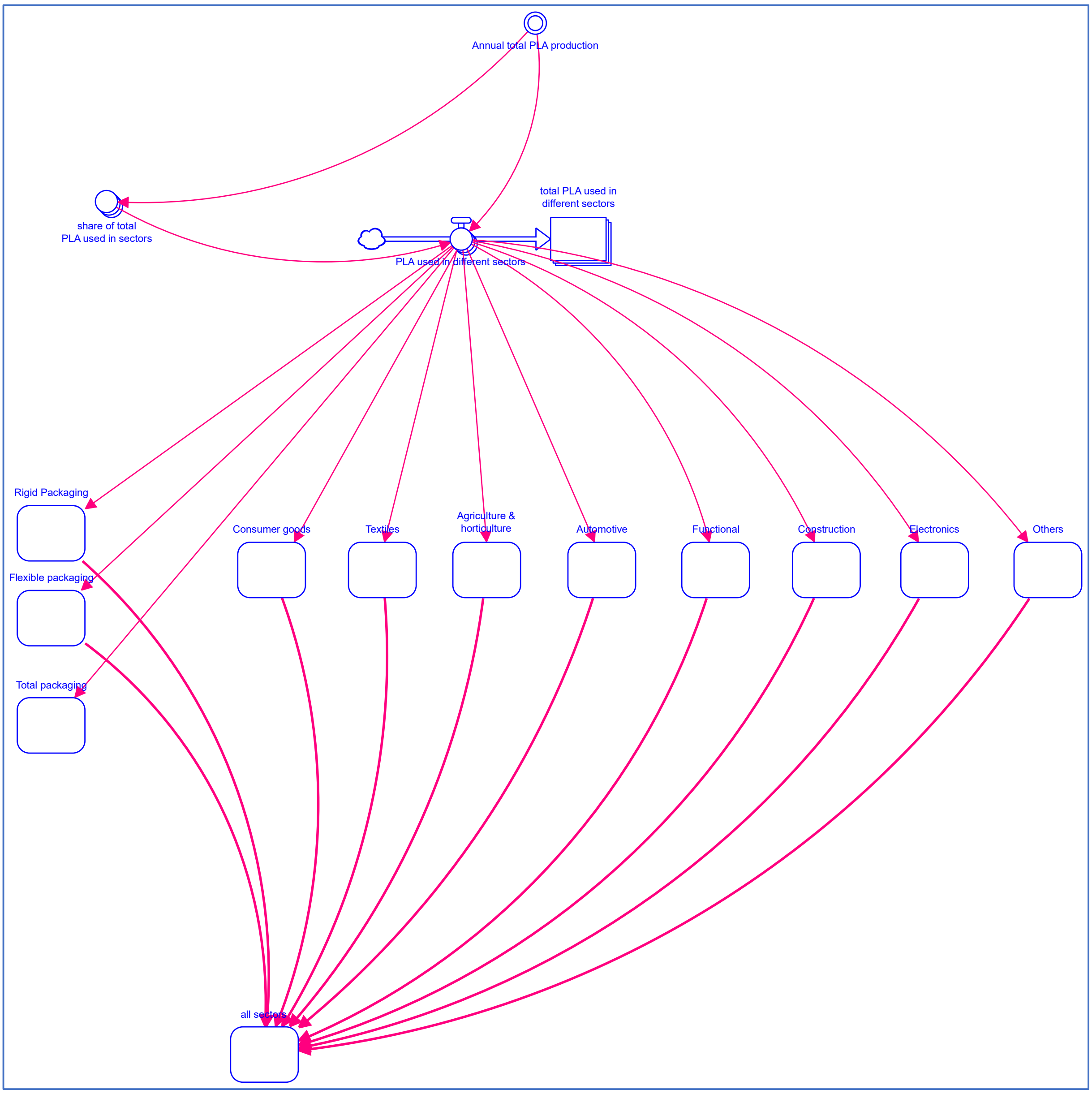

Figure 13: Total amount of PLA produced is used in ten different industrial sectors each presented with a separate module. Source: own illustration

PLA used in different sectors:

The amount of PLA used in different sectors (ton/year) is calculated with an array function in the SyD-ProBio model with the formula:

*PLA_used_in_different_sectors[Sectors] = Annual_total_PLA_production*share_of_total_PLA_used_in_sectors*

where:

share_of_total_PLA_used_in_sectors is determined based on the data obtained from European Bioplastics market data on global production capacities of bioplastics by market segment for 2017 and 2022 (Figure 14).

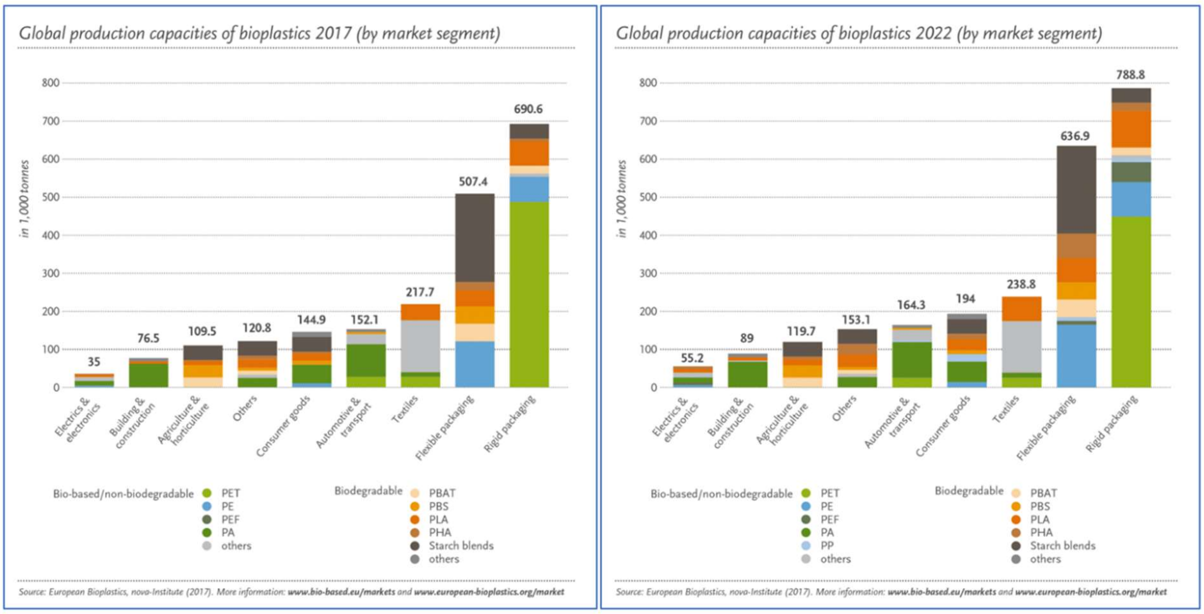

Figure 14: Global production capacities of bioplastics by market segment for 2017 and 2022. Source: (IfBB, 2019)

Figure 15 illustrates the amount of PLA used in "rigid packaging" module as an example. Once different amounts of PLA are distributed to different sectors, the model assigns different time durations (average life time of average product group in this sector) before the PLA in this sector enters the waste stream. End of Life (EoL) options for the total amount of PLA waste generated include composting, recycling, incineration and landfilling.

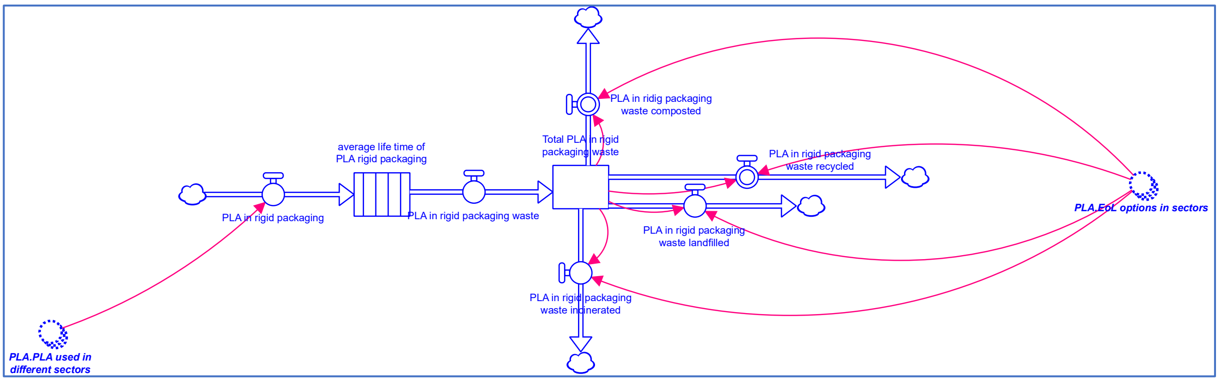

Figure 15: "rigid packaging" module showing PLA used in this sector with alternative EoL options (all other 9 modules for other sectors have the similar structure). Source: own illustration

End of Life (EoL) options in sectors:

Of all the PLA waste generated, the SyD-ProBio model uses a two-dimensional array to assign a value (in percentages) for EoL options and in each sector (Figure 16). To calculate the amount of PLA waste that is composted, for example, the SyD-ProBio model uses the formula:

*PLA_in_ridig_packaging_waste_composted = Total_PLA_in_rigid_packaging_waste*PLA.EoL_options_in_sectors[Rigid_packaging;composting]* where:

PLA.EoL_options_in_sectors[Rigid_packaging;composting] is the percentage of composted PLA waste obtained from the array shown in (Figure 16).

PLA.EoL options in sectors default[*, *]

	recycling	composting	incineration	landfilling
Rigid packaging	0,15	0,2	0,4	0,25
Flexible packaging	0,15	0,2	0,4	0,25
Consumer goods	0,15	0,2	0,4	0,25
Textile	0,15	0,2	0,4	0,25
Agriculture	0,15	0,2	0,4	0,25
Automotive	0,15	0,2	0,4	0,25
Functional	0,15	0,2	0,4	0,25
Construction	0,15	0,2	0,4	0,25
Electronics	0,15	0,2	0,4	0,25
Others	0,15	0,2	0,4	0,25

Figure 16: Percentage of end of life (EoL) options in each of the ten different sectors. Source: own illustration

2.2.4 Global Warming Potential (GWP) of PLA production

Global warming potential of PLA production $\left[{}^{t_{CO2\_eq}}/{}_{t_{PLA}}\right]$, is calculated in the SyD-ProBio model (Figure 17) with the formula:

*GWP_of_PLA_production[Crop_type] = PLA_production*PLA_GWP*

where:

PLA_GWP is the total net cradle-to-factory gate GWP. In the SyD-ProBio this parameter is set to 620 kg CO_{2_eq} per ton of PLA produced from corn. This figure is calculated using a life cycle impact assessment (Vink and Davies, 2015). In the current version of the SyD-ProBio model, this value is assumed to be same for the other four type of crops.

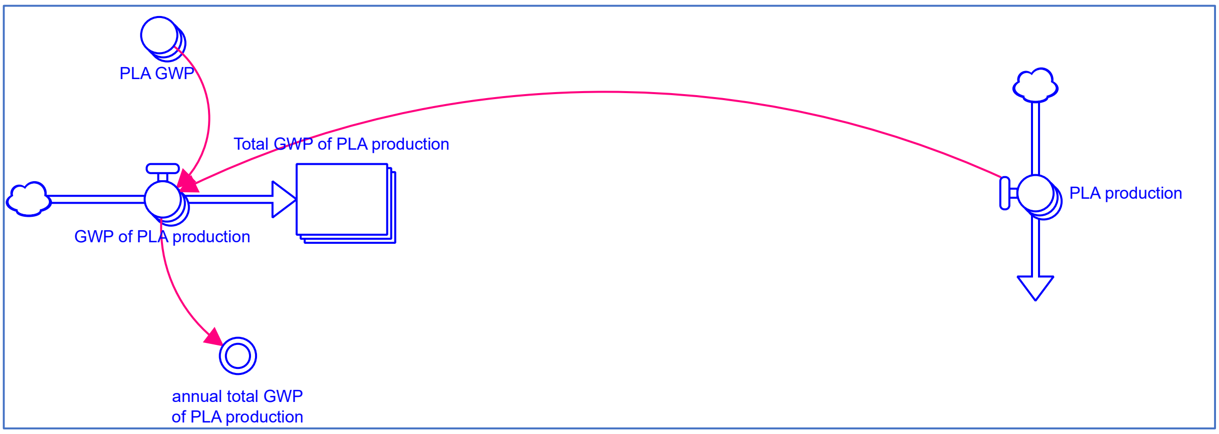

Figure 17: Global Warming Potential of PLA production presented in the SyD-ProBio model. Source: own illustration

2.2.5 Primary Energy from Non-Renewable Resources (PENRR) for PLA production

One of the key global life cycle indicators used in LCA is the use of Primary Energy from Non-Renewable Resources (PENRR). The use of PENRR in PLA production $\left[{}^{MJ}/_{t_{PLA}}\right]$, is calculated in the SyD-ProBio model (Figure 18) with the formula:

*PENRR_use_of_PLA_production[Crop_type] = PLA_production*PLA_PENRR*

where:

PLA_PENRR is the net primary energy from non-renewable resources. In the SyD-ProBio this parameter is set to 40.500 MJ per ton of PLA produced from corn. This figure is calculated using a life cycle impact assessment (Vink and Davies, 2015). In the current version of the SyD-ProBio model, this value is assumed to be same for the other four type of crops.

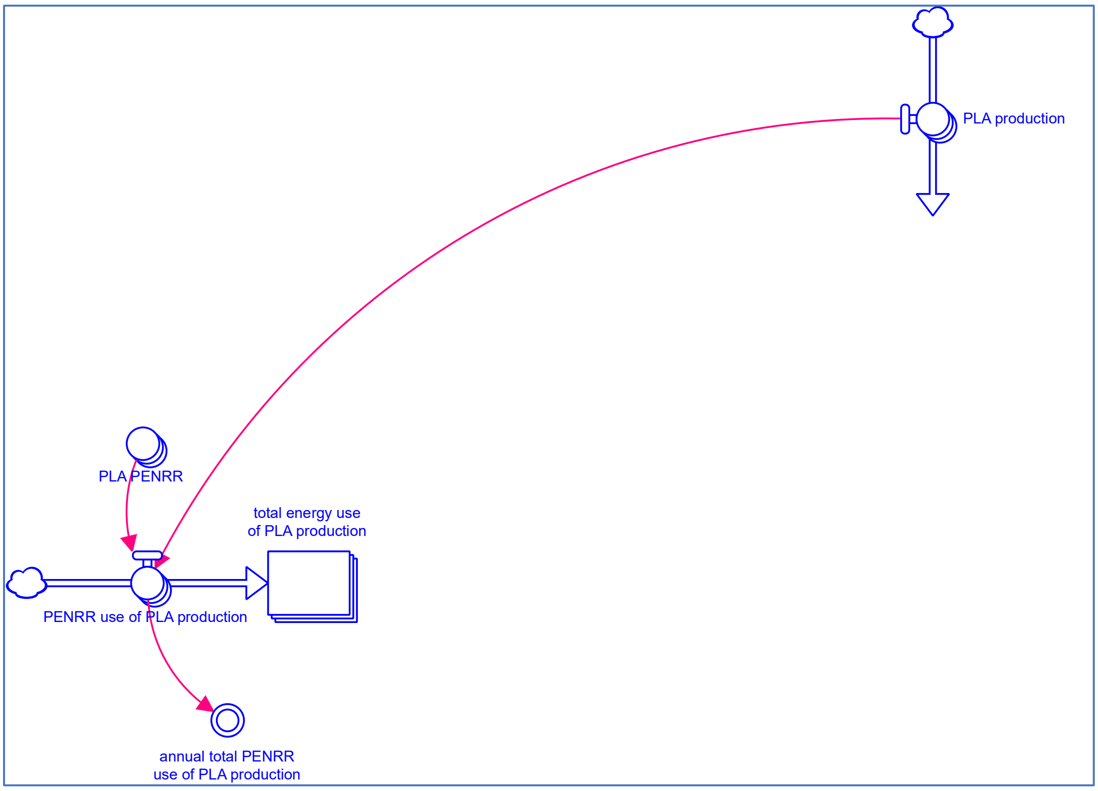

Figure 18: Primary Energy from Non-Renewable Resources (PENRR) of PLA production presented in the SyD-ProBio model. Source: own illustration

2.2.6 PolyPropylene (PP) production

In the PP module of the SyD-ProBio model (Figure 19), the polypropylene production $\left[{}^{t}/_{year}\right]$ is calculated based on the market data on European demand obtained from EuropeanPlastics. The model calculates the PP production with the formula:

PP_production = demand_for_PP-PP_replaced_by_PLA where:

demand_for_PP is the yearly demand for PP in Europe. An initial value of 9.800.000 ton for 2017 is estimated from the market data available. Thereafter, a 3% of increase in the yearly demand is assumed in the model calculations.

PP_replaced_by_PLA is equal to the annual total PLA production with the assumption that all PLA produced substitutes PP in the market.

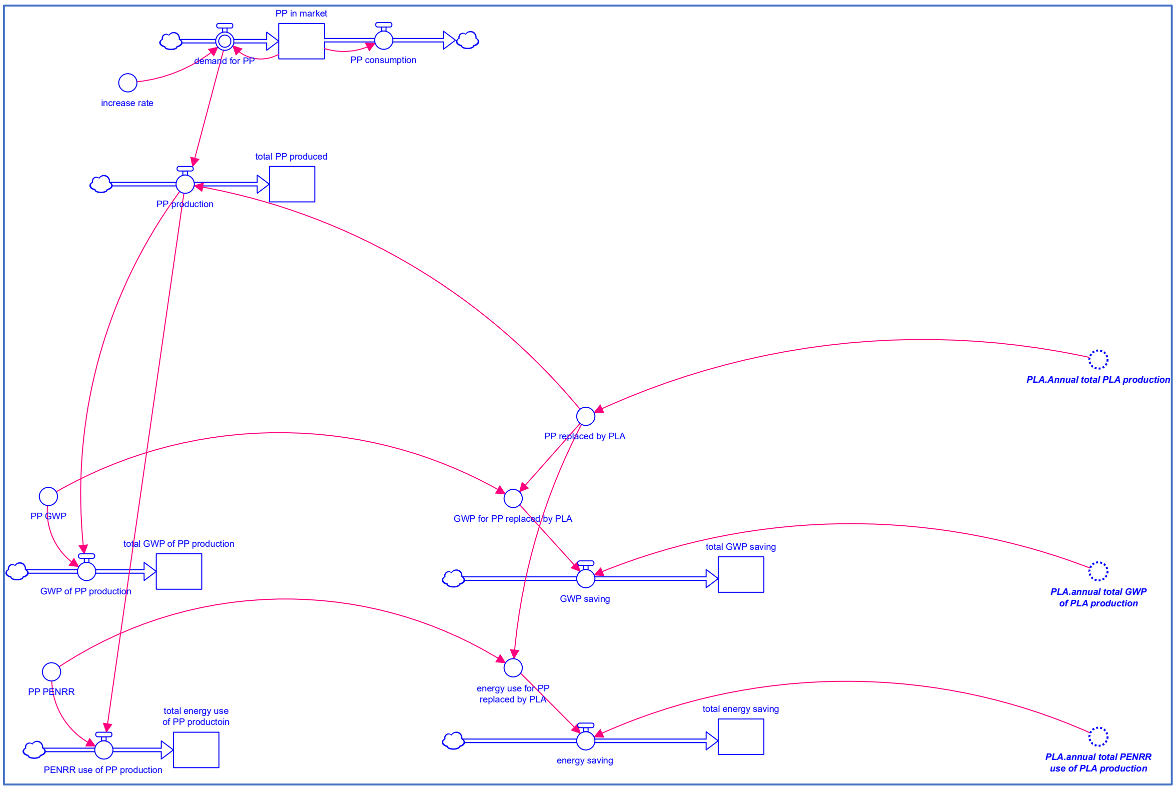

Figure 19: PolyPropylene module of the SyD-ProBio model. Source: own illustration

2.2.7 Global Warming Potential (GWP) of PP production

In the SyD-ProBio model, global warming potential of PP production $\left[{}^{t_{CO2\_eq}}/_{t_{PP}}\right]$, is calculated with the formula:

*GWP_of_PP_production = PP_production*PP_GWP*

where:

PP_GWP is the net global warming potential of producing 1 tonne of PP. In the SyD-ProBio model, this parameter is set to 1.600 kg CO_{2_eq} per ton of PP produced. This figure is based on the life cycle impact assessment studies (Vink and Davies, 2015).

2.2.8 Primary Energy from Non-Renewable Resources (PENRR) for PP production

The use of primary energy from non-renewable resources in PP production $\left[{}^{MJ}/_{t_{PP}}\right]$, is calculated in the SyD-ProBio model with the formula:

*PENRR_use_of_PP_production = PP_production*PP_PENRR*

where:

PP_PENRR is the net primary energy from non-renewable resources. In the model, this parameter is set to 77.000 MJ per ton of PP produced. This figure is based on the life cycle impact assessment studies (Vink and Davies, 2015).

2.3 Scenario definition

The scenario analysis in STAR-ProBio project should provide policy decision support. Thus, the modelling efforts are not undertaken to deliver specific forecasts or decision-making capabilities (Paltsev, 2017), but to highlight changes in impacts, potential risks, benefits and synergies between various scenarios/narratives. Scenarios are defined as a quantitative probabilistic statement of a projected development based on a set of predetermined input parameters including variables representing known and assumed numbers.

For this project we define two sets of predetermined input parameters to calculate two scenarios; (1) On the one hand we describe the Business as Usual (BAU-) scenario, mainly based on existing, well-known and accepted policies (including frameworks and regulations of mandatory and voluntary types). This scenario is compared to the (2) Alternative (ALT-) scenario in which we try to reflect a favourable policy mix for the products discussed in this project as well as for the SAT-ProBio blueprint. For the subsequent description we follow the life-cycle approach (Milios, 2018). Therefore, we collected EU policies and frameworks with a potentially relevant impact on (A) biomass feedstock production and sourcing as well as feedstock supply (in short; primary sourcing), (B) product design and production process, product distribution, (C) product use or consumption and on (D) End of Life (EoL) options. Starting point for the BAU scenario are all documents published in the EU law directory EUR-Lex, the database of the Official Journals of the European Union as summarised in Table 6 in the Annex of this deliverable. To envisage potentially relevant future policy options and/or amendments of existing measures, a more generic literature analysis and stakeholder discussion was undertaken.

In the following we differentiate, for the sake of clarity, between policy measures and policy options, with measures being in place on a European level while policy options encompass upcoming or so far only conceptualised policies or policies which are in place on an individual MS-level and could potentially be implemented on a European level.

For the modelling in the SyD-ProBio tool especially official quantitative objectives are of interest. Such objectives include e.g. a proposed reduction of the 2030 emissions to at least 50% and towards 55% of the 1990 levels from the European Green Deal (EC, 2019), the goal to have an Europe wide secondary raw material with 10 Mio tonnes of recycled plastic established by 2025 according to the Packaging Waste Directive (EU, 2018a) or the launch of a €100 Mio Circular Bioeconomy Thematic Investment Platform mentioned in the current Bioeconomy Strategy (EC, 2018a).

However, only a minority of policy measures and options that are relevant for the market diffusion of increasingly circular and sustainable bio-based materials can be put in numbers, respectively only a minority can be integrated into the SyD-ProBio tool based on a quantifiable impact on the model dynamics.

To be able to provide possible relevant narratives for the transition process towards a bio-based economy, we start by spanning up a room of policy measures and options. The aim is to understand which policies effect which part and parameter of the products life-cycle and to implement quantifiable relationships into the SyD-ProBio tool, keeping in mind and on the radar non-quantifiable policies. Therefore, the most important policy measures and options are assigned to the different life-cycle stages (primary sourcing, production process, product use and End of Life) and categorized based on the typology illustrated in Figure 20.

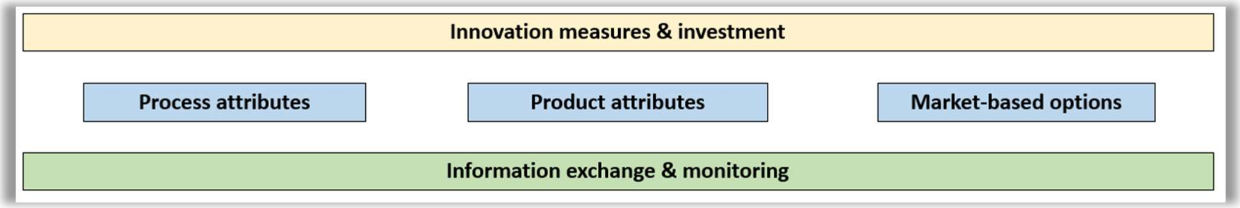

Figure 20: Used typology for the categorisation of policy options. Source: own illustration

Horizontal enabling measures and options include information innovation measures & investments as well as exchange & monitoring. The former includes e.g. the Horizon 2020 and the Horizon Europe research and development subsidies or the development of a sustainability taxonomy for financing and investments (TEG, 2020). The latter captures the EC`s efforts to enhance accessible knowledge through the Knowledge Centre for Bioeconomy as well as European Bioeconomy Forums in the MS (EC, 2018b) but also the definition and monitoring of Common Agricultural Policy (CAP) indicators such the sustainable use of pesticides indicator or the development and implementation of a "Farm Sustainability Tool for Nutrients" (FaST) for farmers based on a digital tool allowing for the communication with the Integrated Administration and Control System and a Land Parcel Identification System (EC, 2018c).

Vertical measures include measures and options that can directly influence production process or product related attributes or are designed to have an impact on the market and purchasing decisions. Relevant examples attributing to the process include e.g. the EU Eco-Management and Audit Scheme (EMAS) for companies and other organizations to evaluate, report, and improve their environmental performance (EU, 2018b) or Best Available Technologies (BAT) reference documents defining emission limit values for a list of polluting substances to air and water where MS are required to monitor, determine and enforce adequate penalties if industrial processes do not meet these limits (EU, 2019a). Relevant examples attributing to the product itself include e.g. any certificates, labels and norms such as the Product Environmental Footprint (PEF) Category Rules which include also rules for some bio-based product categories (e.g. paints, detergents, packed water, T-shirts, thermal insulation) tested in the Commission`s Single Market for Green Products initiative pilot-phase between 2013-2018 (EC, 2013). Market relevant examples are furthermore any taxes or tax incentives, emission trading (ETS) or extended producer responsibility (EPR) schemes.

While the, in Figure 20 presented categories are not perfectly mutually exclusive, each category includes more or less quantifiable policy measures and options. In the following Table 1 - Table 4, the policy measures (for the BAU-scenario) and options (for the ALT-scenario) are assigned to the different life-cycle stages for increasingly circular and sustainable biobased materials. In the following we will discuss a selection of policies that will likely have the most direct and/or even quantifiable/measurable impact on the bioeconomy sector in question to outline the differences in the two narratives namely the BAU- and the ALT-scenarios.

BAU-Scenario; The current policy framework does not have any measures in place to boost the production of bio-based polymers in general or of specific bio-based polymer products. Regulations addressing the phase-out of fossil-based chemicals on the other hand mainly address the phase-out of certain products. The Single-Use Plastics Directive e.g. focuses on “products that are found the most on beaches […]” which are not designed for re-use or cost-effective recycling “as well as fishing gear containing plastic and products made from oxo-degradable plastic.” The Directive lists products in its Annex grouped by the intervention needs namely consumption reduction, restrictions on placing on the market, improving product requirements, improving marking requirements, extended producer responsibility (EPR)-schemes, separate collection and awareness raising. These products include e.g. tobacco product filters, beverage bottles or composite beverage packaging, caps and lids used for beverage containers, sanitary towels, tampons and applicators and lightweight plastic carrier bags. While the directive excludes naturally occurring polymers, modified natural polymers as well as plastics manufactured from bio-based starting substances are covered. Measurable quantitative consumption reduction should be achieved by the member states by 2026 compared to 2022. Therefore, a methodology for the calculation and verification of ambitious and sustained reduction will be laid down by the beginning of 2021. An evaluation of this directive is suggested for assessing “possible further measures, including the setting of Union-wide reduction targets for 2030 and beyond […]”. (EU, 2019b)

The Commission`s Single Market for Green Products initiative run a pilot-phase between 2013-2018, to propose methods as a common way of measuring environmental performances of different products and organizations. The developed Product Environmental Footprint (PEF) Category Rules include rules for some bio-based product categories (e.g. paints, detergents, packed water, T-shirts, thermal insulation). In the currently running second phase, the Commission assesses “whether the methods, product and sector performance benchmarks, and incentives were successful so that they can be applied in policy tools.” (EC, 2013) Guidelines based on the EU Green Public Procurement Directive include mainly label proposed in the EU Ecolabel directive with bio-based categories for personal care products, detergents, clothing and textile products, paints and varnishes, furniture and bed mattresses, gardening products, lubricants and paper products and set thresholds sometimes expressed e.g. as minimum percentage of FSC or PEFC certified wood in the product. (EuCo, 2010)

In terms of an increasingly sustainable production especially the European Innovation Partnership (EIP) for agricultural productivity and sustainability can be mentioned including “interested actors such as farmers, researchers, advisors and businesses involved in the agriculture and food sector” to promote “a resource efficient, economically viable, productive […] agricultural and forestry sector”. The Common Monitoring and Evaluation Framework (CMEF) was set-up to assess whether the Common Agricultural Policy (CAP) is achieving its objectives. (EU, 2014) Standards of good agricultural and environmental condition of land (GAECs) are be adopted on a national level “taking account of the specific characteristics of the areas concerned”, including e.g. the protection and management of water. (EuCo, 2013) Furthermore, the 32.5% energy efficiency target by 2030 with possible upwards revisions in 2023 based on the energy efficiency directive (EU, 2018c) as well as the 32% renewable energy shares according to the 2nd renewable energy directive (EU, 2018d) are corner stones with a potential direct quantitative impact for the sustainability of the production process. Especially for bio-based chemicals produced in medium scaled industrial complexes outside of the ETS-scheme, the lower emissions reduction targets (30% instead of 42% by 2030) compared to large-scale refineries which are object to the trading scheme may provide a facilitation where large-scale refinery efficiencies pose a challenging competition. The Industrial Emissions Directive (IED) “lays down rules on integrated prevention and control of pollution arising from industrial activities.” Among other sectors, this directive includes the production of organic chemicals including plastic materials and waste management in general. Best available technologies (BAT) reference documents define emission limit values for a list of polluting substances to air and water and MS are required to monitor and to determine and enforce adequate penalties. (EC, 2010)

Most concrete measures are put in place on a European level with regard to the end-of-life of products and circularity. The Waste Framework Directive defines the waste hierarchy as the priority order in waste prevention and management legislation and policy: (1) prevention, (2) preparing for re-use, (3) recycling, (4) other recovery, e.g. energy recovery and (5) disposal. To ensure that waste undergoes recovery operations "waste shall be collected separately if technically, environmentally and economically practicable". Therefore, MS should "set up separate collection for at least paper, metal, plastic and glass waste […] and should introduce separate collection of biowaste, hazardous waste produced by households and textile waste." While this obligation was set with a deadline in 2015, separate collection e.g. for hazardous waste fractions produced by households as well as textiles are to be set up by 2025. By the end of 2023, MS shall ensure that "bio-waste is either separated and recycled at source, or is collected separately and is not mixed with other types of waste". This waste stream may also include "waste with similar biodegradability and composability properties which complies with relevant European standards". Annex IVa of this directive furthermore, lists economic instruments and other measures to provide incentives for the application of the waste hierarchy and discusses minimum requirements for EPR-schemes. (EU, 2018e)

Based on the Packaging and Packaging Waste Directive, the MS have to ensure that systems are set up to provide for returning or collecting used packaging/packaging waste. Furthermore, MS have to ensure by the end of 2024, that EPR-schemes are established for packaging. (EU, 2018a) The Single-Use Plastics Directive asks the MS to ensure the separate collection for recycling by 2025 of 77% and by 2029 of 90% by weight of single-use plastic products placed on the market. Deposit-refund schemes and collection targets for relevant EPR-schemes are recommended to reach these goals. (EU, 2018a)
The Waste Directive sets the following targets for 2020: The "preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households and possibly from other origins […] shall be increased to a minimum of overall 50% by weight" and "the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials […] shall be increased to a minimum of 70% by weight. For the years 2025, 2030 and 2035 preparation for re-use and the recycling of municipal waste shall be increased to a minimum of 55%, 60% and 65% by weight respectively. Further, "re-use and recycling targets for construction and demolition waste and its material-specific fractions, textile waste, commercial waste, non-hazardous industrial waste and other waste streams" will be assessed by the Commission by the end of 2024. (EU, 2018e) The packaging and packaging waste directive sets the target of a minimum of 65% of weight of all packaging waste to be recycled by the end of 2025. This includes a minimum recycling target of 50% for plastic packaging. By the end of 2030 the target increases to 70% of all packaging waste and 55% for plastic in particular. However, MS have the possibility to postpone the deadlines for attaining the targets in specific case by a total of 15 percentage points (for the single targets not below 30%). (EU, 2018a)

ALT-Scenario; In a position paper European Bioplastics calls on the Council and the Parliament to also include concrete actions to support the substitution of fossil-based with bio-based plastics. These actions should include a revised Packaging and Packaging Waste Directive ensuring a 10% share of bio-based plastic packaging materials by 2030. (EUBP, 2018) Relevant market-based instruments include taxes and fees with the effect of reducing consumption of certain products, namely fossi-based chemicals. The EU Plastic Strategy discusses the exploration of "the feasibility of introducing measures of a fiscal nature at the EU level" for single-use plastics. (EC, 2018d) Measures already implemented in some countries could be theoretically extended to a European level. According to the OECD Working Papers on Sustainable Plastics, Denmark is applying a dedicated tax on soft PVC items and several MS (BE, DK, ES, FI, LT, NL, SL) to plastic packaging sometimes with higher rates for single-use plastic items. Single use plastic bag taxes or charges are found in France, Ireland and Portugal. Italy had a tax already in 1993 on plastic bags which were not biologically decomposable, which is however not in place any longer. A UK plastic bag charge resulted in a reduction of 83% consumption. Examples of bans in various MS include the Netherlands where the "government banned the free handout of plastic bags with purchases to stimulate more circular products to be used, or to reuse earlier purchased plastic bags", Italy where it is forbidden to "market and produce on the national territory the sticks for cleaning the ears that have the support in plastic or in non-biodegradable and compostable material", France having banned BPA in baby bottles at an relatively early stage and extending this ban now on all packaging intended to come into contact with food as well as several countries banning the use of microbeads in cosmetics (NL, US, CA, AU, UK, IR, NZ, IT). (OECD, 2019)

While the Green Deal states that further legislation and guidance will be proposed on green public purchasing, the Bioeconomy Strategy recommends to promote bio-based materials and products which are not yet addressed in the Green Public Procurement criteria and EU Ecolabel as well as to develop further innovative procurement activities. Furthermore, the EU Emissions Trading System Innovation Fund will help to deploy large-scale innovation projects in EU industry including `climate and resource frontrunners` to "develop the first commercial applications of breakthrough technologies in key industrial sectors by 2030." Furthermore, the "Commission will present a Sustainable Europe Investment Plan [combining] dedicated financing to support sustainable investment, and proposals for an improved enabling framework that is conducive to green investment. National budgets will be addressed through screening and benchmarking green budgeting practices, "the review of the European economic governance framework will include a reference to green public investment in the context of the quality of public finance." A minimum of 30% of the InvestEU Fund is proposed to contribute to fighting climate change with projects being "subject to sustainability proofing to screen the contribution that they make to climate, environmental and social objectives." Cooperation with the European Investment Bank (EIB) Group is envisaged. "The EIB set itself the target of doubling its climate target from 25% to 50% by 2025, thus becoming Europe's climate bank." (EC, 2019, 2018a).

In terms of an increasingly sustainable production the CAP proposal includes the use of a "Farm Sustainability Tool for Nutrients" (FaST) for farmers based on a digital tool allowing for the communication with the Integrated Administration and Control System and a Land Parcel Identification System. The tool will allow nutrients balance management and to gather relevant management practices, crop history, yield goals and indications regarding legal limits and requirements relevant to farm nutrients management and for a further Integrated Nutrient Management Plan. (EC, 2018c) Furthermore, the Bioeconomy strategy mentions EUR 10 billion foreseen for the Horizon Europe cluster for "Food and Natural Resources" running from 2021-2027. Research and innovation funding of the previous European programmes in this sector have been significantly smaller with EUR 3,9 billion for the Societal Challenge 2 in Horizon 2020 (2014 – 2020) and EUR 1,9 billion in the FP7 (2007-2013). (EC, 2018a) With regard to bio-based polymers possibly based on cellulose derived building blocks, the Green Deal proposal states regulatory and other measures "to promote imported products and value chains that do not involve deforestation and forest degradation". Furthermore, the proposal aims at improving greenhouse gas emissions reduction targets to 50-55% by 2030 compared to 1990-levels. (EC, 2019)

The new Circular Economy Action Plan highlights the implementation of EPRs with the aim to "halve the amount of residual (non-recycled) municipal waste by 2030. Furthermore, "product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout the lifecycle" should be incentivized. Also, a market observatory for key secondary materials should facilitate the establishment of an intra-European secondary materials market for recycling while restricting exports to third countries. Targets and waste prevention measures are discussed to reduce (packaging and packaging waste and to reduce the complexity of packaging materials. Therefore, also a harmonized EU-wide separate collection system will be assessed. Intentionally added microplastics could be restricted via the European Chemicals Agency, and biodegradable or compostable plastics and bio-based plastics could be applied where they result in "genuine environmental benefits, going beyond reduction in using fossil resources." (EC, 2020)

Table 1: Policy measures and option packages for the BAU and the ALT scenario respectively. Source: own illustration

A – Primary sourcing SyD-Parameters: Yield efficiency (& nutrients use); Water use; Pesticides use and nutrients runoff; Energy intensity		
	BAU policy measures	**ALT policy options**
Innovation & Investments	• European Innovation Partnership (EIP) for agricultural productivity & sustainability • EIP network on sustainable water management • Investment from European Agriculture Fund for Rural Development (EAFRD) based on min. gains in water efficiency between 5%-25%	• Merging EIP with Network for Rural Development into Common Agricultural Policy (CAP) network • EUR 10 billion for Horizon Europe cluster "Food and Natural Resources" • Africa-Europe Alliance • Neighbourhood, Development and International Cooperation Instrument
Process attributes	• TFEU states first objective of CAP to continuously increase agricultural productivity • Standards of good agricultural and environmental condition of land (GAECs) • National Action Plans on nutrients	• Statuary Management Requirements include control, buffer strips • Integrated Nutrient Management Plan • Deforestation free supply chains
Product attributes	• Organic products standards & labelling in case of soil fertility management, recycling organic materials and cultivation techniques	• Certification of carbon removals based on robust and transparent carbon accounting (World resource institutes GHG-protocol on carbon losses and UNFCC methodologies for carbon credits. Sustainable Agriculture Land Management (SALM), Voluntary Carbon Standards (VCS) • Establishment of sustainability safeguards to avoid negative impacts due to direct land use change (e.g. deforestation).
Market-based		• Pricing policies based on water efficiency targets • Carbon pricing for biomass feedstock
Information exchange & monitoring	• Common Monitoring and Evaluation Framework (CMEF) • Performance metrices incl. agricultural productivity • CAP indicator percentage of land using fertiliser/pesticide, water quality indicator • CMEF-indicator on irrigated land, indicator on water abstraction	• Farm Sustainable Tool for Nutrients (FaST) • Better SAPM-indicators, water accounts based on the Water Information System for Europe (WISE) • Water Exploitation Index Plus

Table 2: Policy measures and option packages for the BAU and the ALT scenario respectively. Policy measures and options in a fat font exhibit a direct, quantifiable and/or measurable relation with existing or implementable parameters in the SyD-tool. Source: own illustration

B – Production process **SyD-Parameters: Production (renewable) energy intensity; Product resource efficiency**		
	BAU policy measures	**ALT policy options**
Innovation & investments	• EUR 100 million Circular Bioeconomy Thematic Investment Platform • Biobased Industries Joint Undertaking (BBI JU) • European Fund for Strategic Investments • Public Private Partnerships	• Sustainable taxonomy and green bonds • ETS Innovation Fund deploying large-scale innovation projects • **Sustainable Europe Investment Plan; >30% of InvestEU fund to fight Climate Change; cooperation with EIP – 50% climate target by 2025** • SME Initial Public Offerings Fund
Process attributes	• **30% emission reduction (outside the ETS-scheme), 32% renewable energy share, 32.5% energy efficiency increase in 2030** • **Effort sharing based renewables targets** • **Plastic Packaging waste - 55% from recycling, EU pledging campaign to reach 6.4 Mio t in 2025** • Best Available Techniques (BAT) reference documents	• **Green Deal: 50-55% emission reductions** • **EU pledging campaign goal 10 Mio t in 2025 recycled plastic = secondary raw materials** • New eco-design measures for recyclability • EU Environmental Technology Verification scheme as EU certification mark • **DE: doubling resource productivity by 2020 (to 1994)**
Product attributes		• Harmonised rules for labelling biodegradable • „Right to repair“ • Fight against premature built-in obsolescence
Market-based	• Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) – “no data no market” principle	
Information exchange & monitoring	• European Chemicals Agency (ECHA) central database for manufacturers and importers regarding the properties of their chemical substances	• Circular Plastics Alliance enforcement on recycled content and waste reduction measures • Promoting digital technologies for tracking, tracing and mapping of resources • Market observatory for key secondary materials

Table 3: Policy measures and option packages for the BAU and the ALT scenario respectively. Policy measures and options in a fat font exhibit a direct, quantifiable and/or measurable relation with existing or implementable parameters in the SyD-tool. Source: own illustration

C – Product distribution/use SyD-Parameters: fossil-based chemicals consumption/phase-out; Fossil-based chemicals substitution		
	BAU policy measures	**ALT policy options**
Innovation & investments		• Green Public Procurement (GPP) guidelines to incl. bio-based products • US: Bioreferred • BE (Flanders): 100% sustainable and 3% innovative public procurement by 2020
Process attributes		• “Sustainable products policy” to support circular design of all products • Mandatory essential requirements for packaging • Restricting intentionally added microplastics • BE: Full circularity by 2050 incl. material flows, energy, water, food and space
Product attributes	• **Measurable quantitative reduction by MS in 2026 for single-use plastics** • **Ban on Bisphenol A (BPA) in baby bottles** • EU Ecolabel bio-based categories for personal care products, detergents, clothing and textile products, paints and varnishes, furniture and bed mattresses, gardening products, lubricants and paper products	• **EUBP 10% share of bio-based packaging materials by 2030** • Sourcing, labelling and use of bio-based plastics beyond fossil-based substitution • Standardisation of labels “biodegradable” and “compostable” • Restricting single-use • Product environmental footprint (PEF) for chemicals • Sustainability certification, eco-labelling, ecodesign beyond energy-related products, sustainability principles, standardization • Electronic product passport • Incentivising “products as a service”
Market-based		• Carbon borders and trade deals • Carbon tax • Taxes and charges on specific Single use Plastic (SuP) products already in various countries (DK, UK, IT, FR. NL, US, CA, NZ, IR, UK, AU)
Information exchange & monitoring	• Knowledge Centre for Bioeconomy • Methodology for monitoring implementation of Single Use Plastics (SuP)-Directive in 2021	• National budgets addressed through screening and benchmarking green budgeting practices

Table 4: Policy measures and option packages for the BAU and the ALT scenario respectively. Policy measures and options in a fat font exhibit a direct, quantifiable and/or measurable relation with existing or implementable parameters in the SyD-tool. Source: own illustration

D – End of Life (EoL) **SyD-Parameters: Return, collection and recovery; Recycling and Reuse; Landfilling and marine litter, waste trade**		
	BAU policy measures	**ALT policy options**
Innovation & investments	• EUR 100 million Circular Bioeconomy Thematic Investment Platform	• EU Emission Tradings Scheme (ETS) Innovation Fund
Process attributes	• **Separate collection for at least household paper, metal, plastic and glass by 2015, household hazardous wastes, textiles by 2025, no mixing of bio-waste with 2023** • **SuP 90% by weight separate collection by 2029** • **By 2035 landfilling of municipal waste in general should be reduced to 10%, restriction recommended for waste streams to separate collection**	• EU-wide model for harmonized separate waste collection • Eradicate illegal and non-compliant landfills • Development of certification scheme for recycling plants in the EU and in third countries • **Chinas National Sword Policy banning 24 types of solid waste, including various plastics** • **FR: reduce by half the amount of landfilled waste by 2025**
Product attributes	• **60% increase of municipal waste for re-use and recycling by 2030** • **packaging and packaging waste recycling target of 70% increase by 2030 (55% for plastic)**	• **Re-use and recycling targets for construction and demolition waste, textile waste, commercial waste, non-hazardous industrial waste and other (to be revised by 2024)** • **Mandatory recycled contents**
Market-based	• Minimum requirements for EPR-schemes, by 2024 EPR for packaging, EPR and Deposit Refund Schemes (DRS) for SuP • **Basel ban on waste trade outside of EU/OECD**	• **EPR for materials or products for halving residual municipal waste by 2030** • **Stop exports of wastes outside the EU** • Facilitate shipments within the EU • Chinese restrictions on waste imports
Information exchange & monitoring	• Circular Economy Monitoring framework • European Circular Economy Stakeholder Platform • Circular Economy Finance Support Platform	• Info sharing, inspiration and fostering public understanding of the threat of climate change • Real and virtual spaces • Encourage participants to commit to specific goals; capacity buildings for facilitation of grassroots initiatives, educational modules • European Dataspace for Smart Circular Applications

3. RESULTS

3.1 The SyD-ProBio model user interface

The SyD-ProBio model puts forward a user-friendly interface (Figure 21). Any user interested in SyD-ProBio model, can find background information to the model (i.e. system boundaries, model structure and formulation, key assumptions, policy options tested etc.) by accessing the "**About the Model**" section.

The "**Simulation Lab**" section allows the model users to develop and run their own alternative scenarios. This gives the users the chance to test a wide range of policy options affecting, directly or indirectly, the market uptake of PLA in Europe.

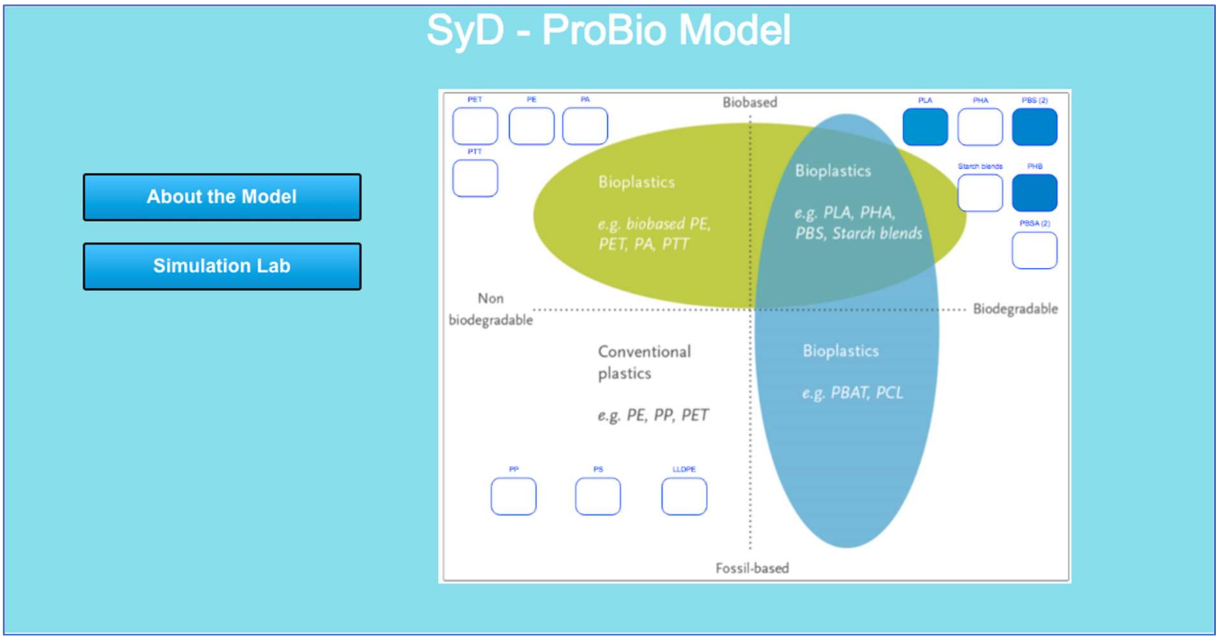

Figure 21: SyD-ProBio Model user interface – HOME page. Source: own illustration, SyD-ProBio

Once clicked on the "Simulation Lab" button, a top navigation bar allows the SyD-ProBio model user to switch between different pages in the user interface. These pages are:

1. HOME
2. Land Use
3. Water Use
4. Crop Yield
5. Polylactic Acid (PLA) Production
6. Polypropylene (PP) Production
7. Global Warming Potential (GWP)
8. Primary Energy of Non-Renewable Resources (PENRR)
9. ALL POLICY OPTIONS

In each of the pages from number 2 to 8, a centrally located graph shows how selected model parameters change in time. The model user can use the "Run", "Pause", "Resume" and "Stop" buttons located below the central graph anytime to start, modify and end a simulation.

Each of these pages also accommodate a number of devices (e.g. pie-charts, on-off buttons, graphical/numeric inputs, switch buttons, sliders etc.) enabling the model users to customize the default scenario and the underlying key assumptions.

Land Use:

The SyD-ProBio Model considers five different types of crop as feedstock for PLA production. These crops are sugar cane, sugar beet, corn, potato and wheat. By clicking the “Land Use” tab in the upper navigation bar, the model user can see the amount of land required (ha/year) to produce each of the five different types of crops for PLA production (Figure 22).

Figure 22:SyD-ProBio Model Simulation Lab – Land Use page. Source: own illustration, SyD-ProBio

In the “Land Use” page the model user can change the “share of feedstock in the total PLA demand” simply by clicking the pia-chart, and/or the “potential future PLA demand” from ten different sectors (rigid packaging, flexible packaging, consumer products, textile, agriculture, automotive, functional, construction, electronics, others) by clicking the individual sector’s graphical input and changing the future demand in the popped-up graph window (see Figure 23 as an example showing a possible future demand for PLA from rigid packaging sector). The user can also adjust the “crop yield efficiency” by clicking the associated knob.

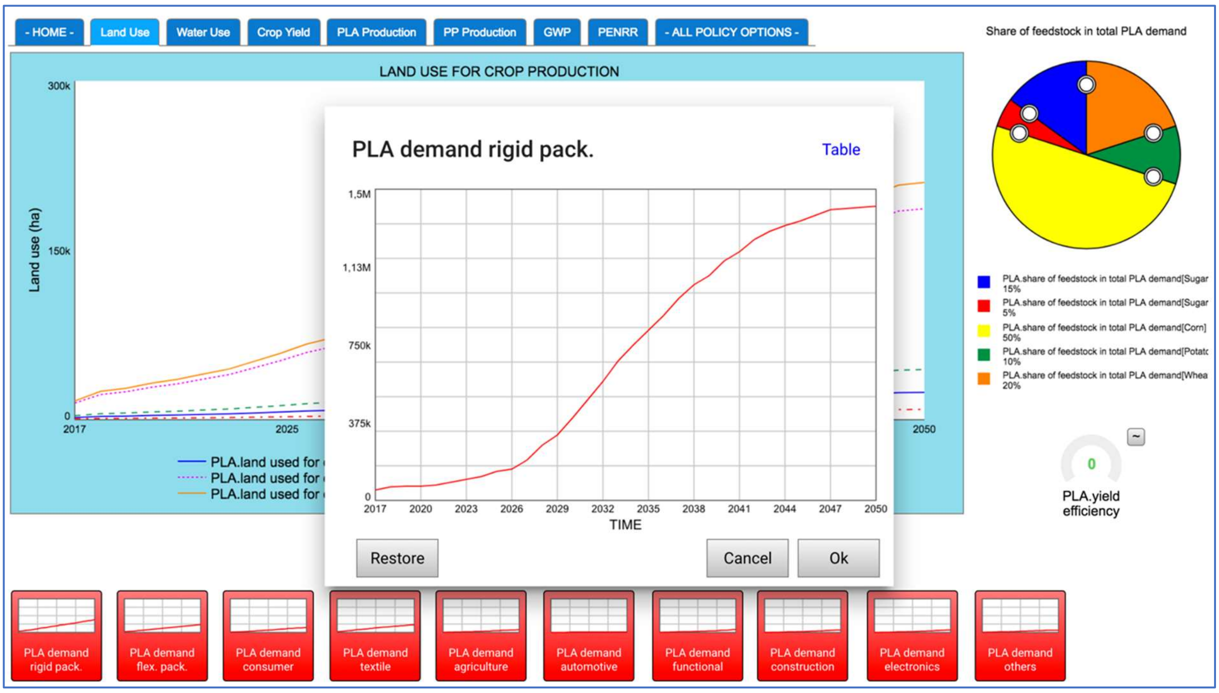

Figure 23: SyD-ProBio Model Simulation Lab – Land Use page. Use of graphical input device to define potential future demand for PLA from e.g. rigid packaging sector. Source: own illustration, SyD-ProBio

Water Use:

By clicking the "Water Use" tab on the upper navigation bar, the model user can see the amount of water required (m^3/year) to produce different types of crops for PLA production (Figure 24).

Similar to the "Land Use" page and as described in above section, the model user has the opportunity to change the "share of feedstock in the total PLA demand", the "potential future PLA demand" from ten different sectors, as well as the "crop yield efficiency".

Figure 24: SyD-ProBio Model Simulation Lab – Water Use page. Source: own illustration, SyD-ProBio

Crop Yield:

“Crop Yield” page shows the amount of yield (ton/year) for each of the five different crop types used for PLA production (Figure 25).

Similar to the “Land Use” and “Water Use” pages and as described in above sections, in the “Crop Yield” page the model user can change the “share of feedstock in the total PLA demand”, the “potential future PLA demand” from ten different sectors, and the “crop yield efficiency”. Crop type specific policy options (e.g. quotas on specific crop production) can be tested in this page.

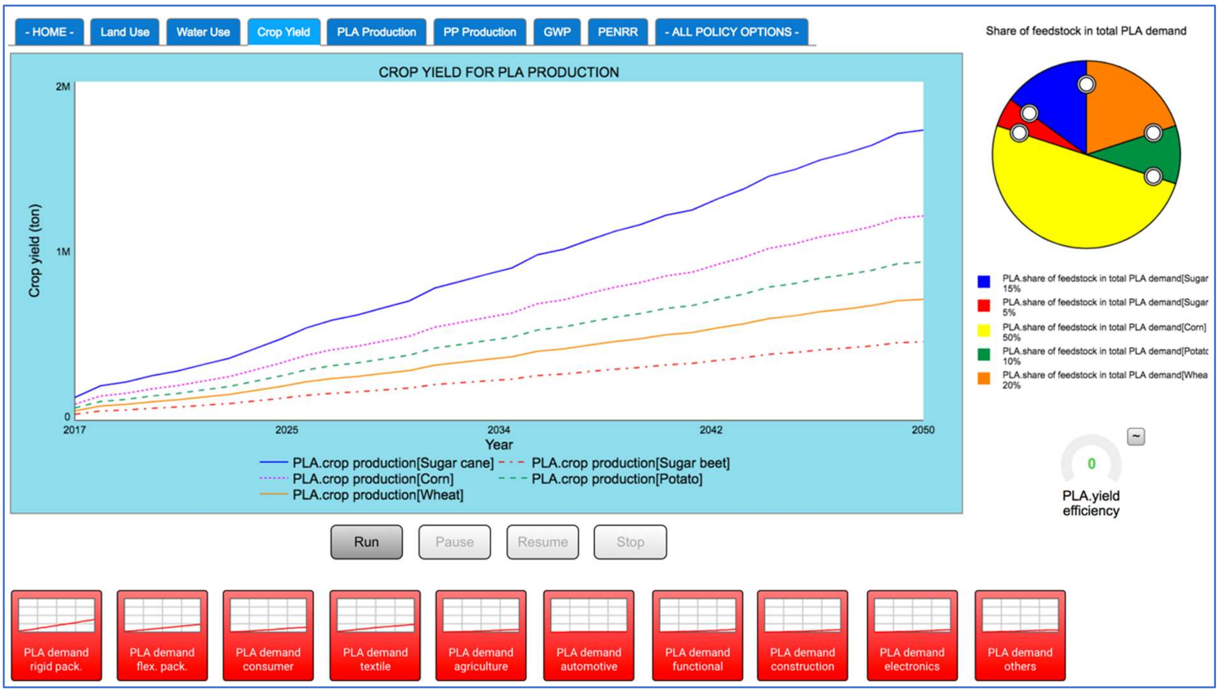

Figure 25: SyD-ProBio Model Simulation Lab – Crop Yield page. Source: own illustration, SyD-ProBio

PLA Production:

The “PLA Production” page shows the PLA production (ton/year) from five different crop types (Figure 26), as well as the recycling of PLA (or any other End of Life (EoL) options i.e. composting, incineration, landfilling) from ten different sectors (Figure 27). The model users can switch between production and recycling graphs by using the tabs on the upper left corner and assess the model simulation results.

The SyD-ProBio model allows the users to customize the existing scenarios depending on the policy options they want to test. Sector specific policies that may affect the future potential demand from specific sector, for instance, can be tested in this page (e.g. subsidies for PLA in agriculture, banning PP in packaging etc.). Additionally, the model users can assess the potential impacts of a sustainability certification scheme, ecolabelling etc. on the demand for PLA as well as on different EoL options. The model users can at any time pause/resume the simulation and change the percentage of “EoL options” for each of the ten different sectors by using the table input device (Figure 28).

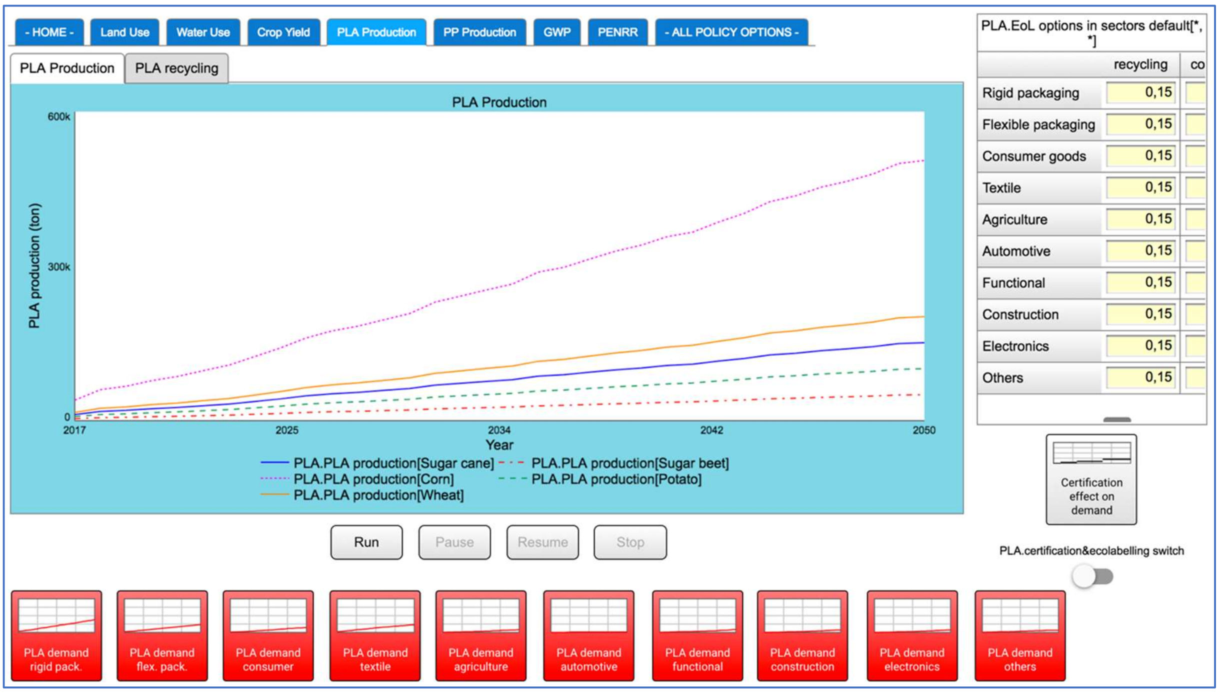

Figure 26: SyD-ProBio Model Simulation Lab – PLA Production page. Source: own illustration, SyD-ProBio

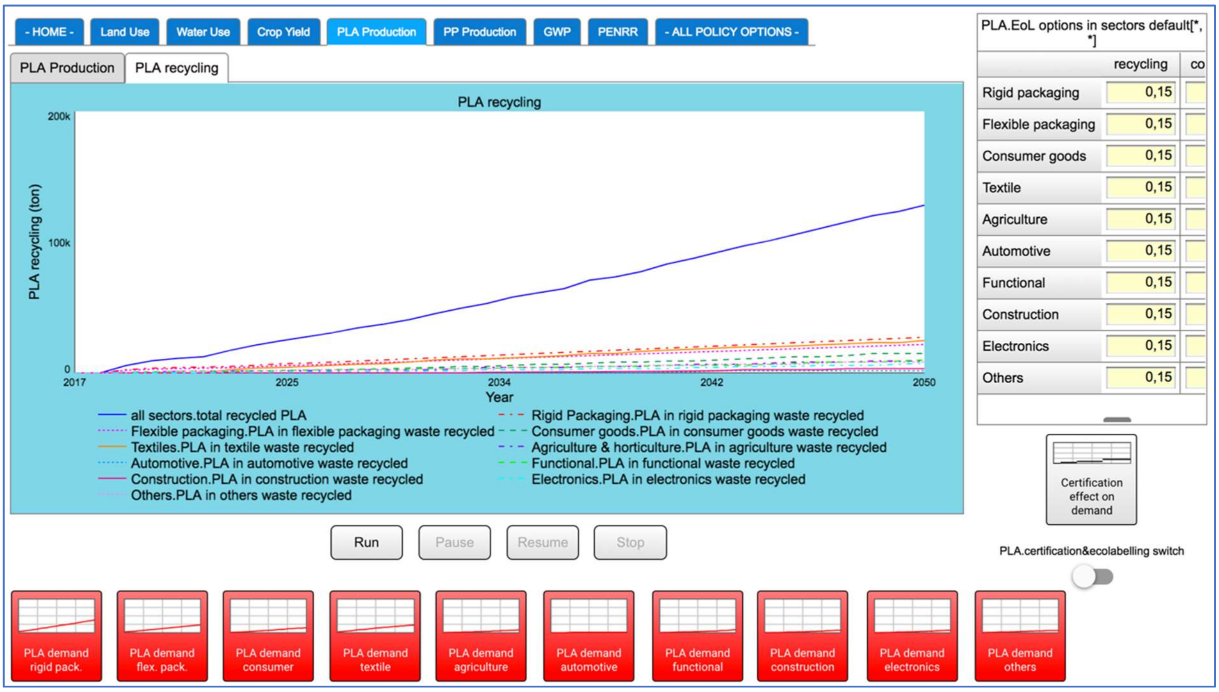

Figure 27: SyD-ProBio Model Simulation Lab – PLA Production page, PLA recycling graph. Source: own illustration, SyD-ProBio

PLA.EoL options in sectors default[*, *]	recycling	composting	incineration	landfilling
Rigid packaging	0,15	0,2	0,4	0,25
Flexible packaging	0,15	0,2	0,4	0,25
Consumer goods	0,15	0,2	0,4	0,25
Textile	0,15	0,2	0,4	0,25
Agriculture	0,15	0,2	0,4	0,25
Automotive	0,15	0,2	0,4	0,25
Functional	0,15	0,2	0,4	0,25
Construction	0,15	0,2	0,4	0,25
Electronics	0,15	0,2	0,4	0,25
Others	0,15	0,2	0,4	0,25

Figure 28: SyD-ProBio Model Simulation Lab – PLA Production page. Use of table input device to define potential future end of life (EoL) options for each of the ten different sectors. Source: own illustration, SyD-ProBio

PolyPropylene (PP) Production:

The "PP Production" page shows the demand for and production of PP (ton/year), as well as the amount of PP that can potentially be replaced by PLA as a consequence of the policy options applied and tested in the SyD-ProBio model (Figure 29).

Policy instruments and measures addressing to phase out oil-based PP (e.g. banning, carbon taxation etc.) that may lead to a decrease in the demand and production of PP can be tested in this page simply by activating the "ban & carbon tax" on-off switch and defining the percentage of reduction in the demand for PP with the graph input device.

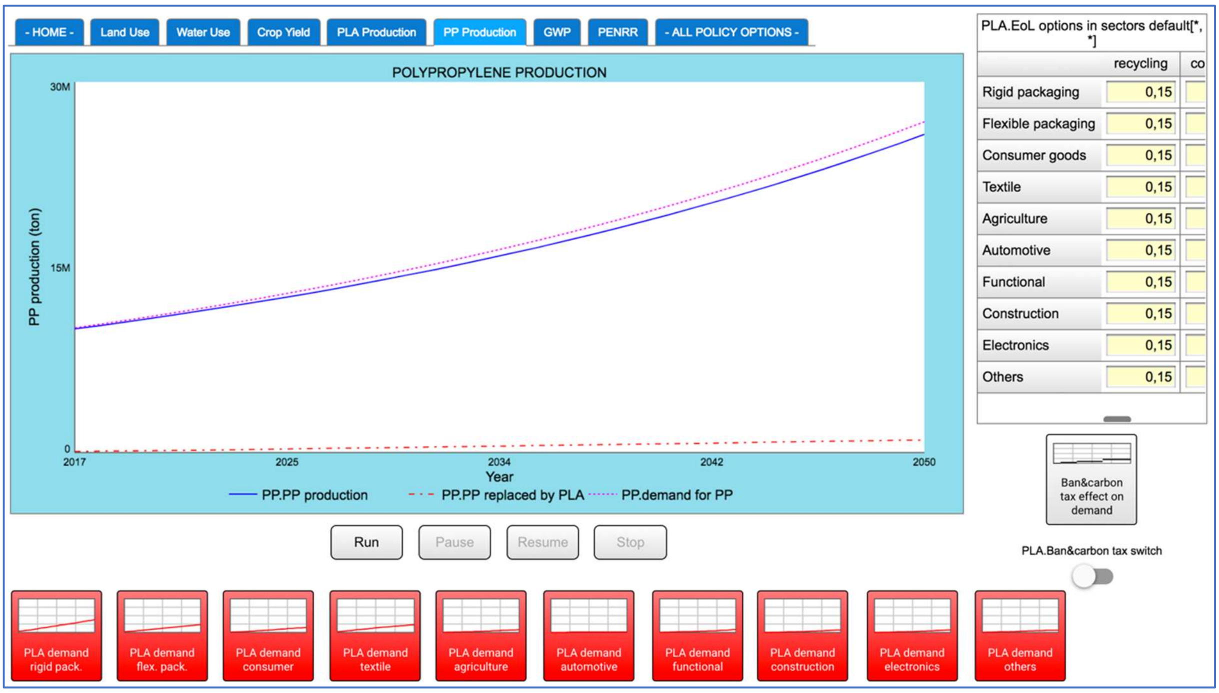

Figure 29: SyD-ProBio Model Simulation Lab – PolyPropylene Production page. Source: own illustration, SyD-ProBio

Global Warming Potential (GWP):

One of the key environmental indicators that SyD-ProBio model allows its users to assess, is the Global Warming Potential (GWP) of PP (ton CO_2 eq./ton PP) and the replacing PLA (ton CO_2 eq./ton PLA). Total GWP calculations are based on the available Life Cycle Analysis (LCA) data. In the GWP page of the model simulation lab, the users have the possibility to change GWP estimates of PLA production from different crop types, as well as the GWP estimate of PP production (Figure 30).

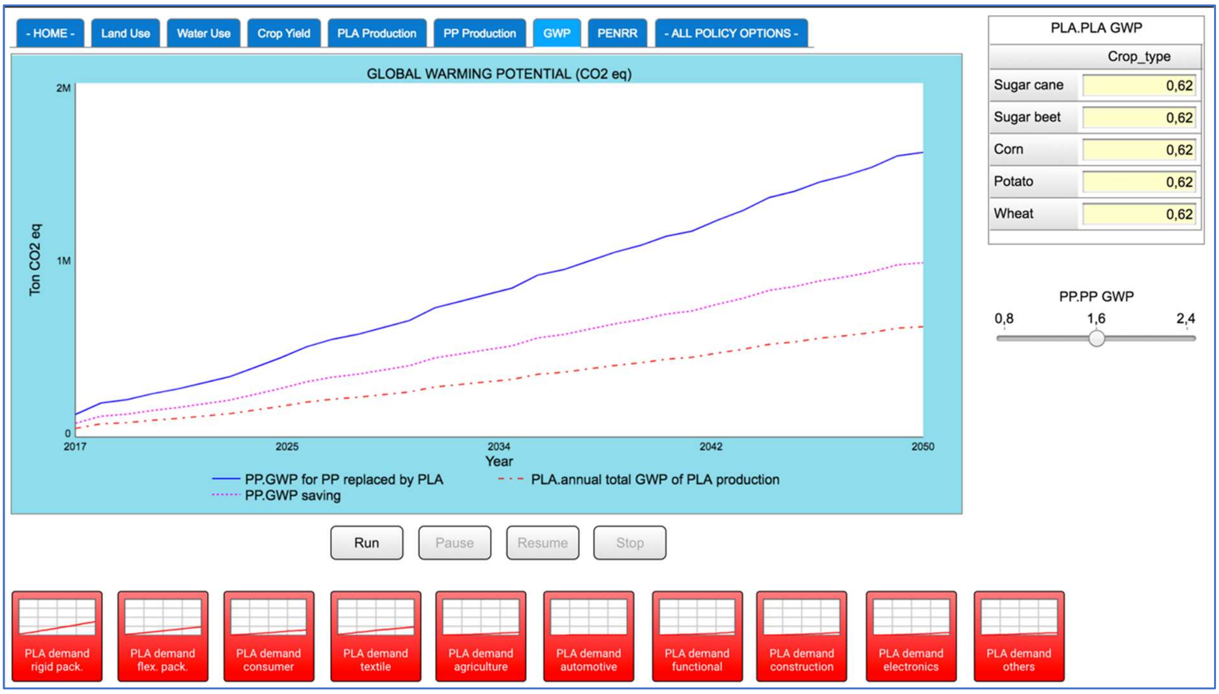

Figure 30: SyD-ProBio Model Simulation Lab – Global Warming Potential (GWP) page. Source: own illustration, SyD-ProBio

Primary Energy of Non-Renewable Resources (PENRR):

Another key environmental indicator to assess in the SyD-ProBio model is the Primary Energy of Non-Renewable Resources (PENRR) use for PP production (GJ/ton PP) and PLA production (GJ/ton PLA).

Total PENRR calculations are also based on the available Life Cycle Analysis (LCA) data and PENRR page allows the model users to change PENRR use estimates for PLA production from different crop types, as well as the PENRR use estimate for PP production with associated table input and slider devices (Figure 31).

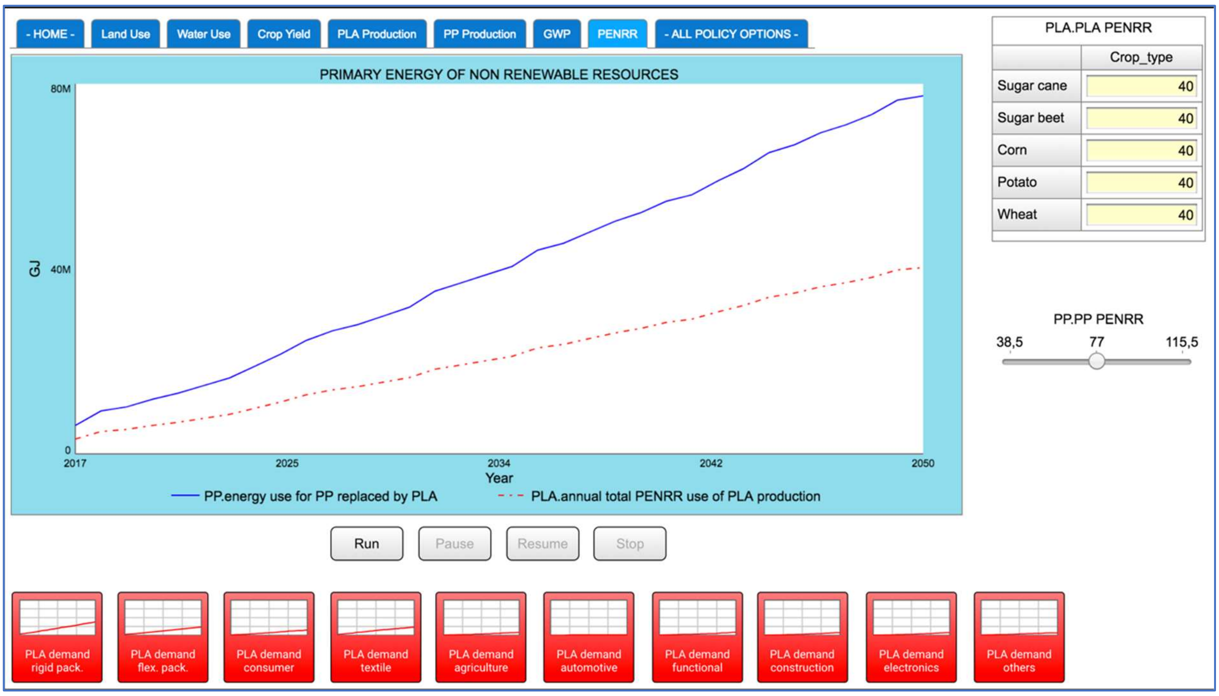

Figure 31: SyD-ProBio Model Simulation Lab – Primary Energy from Non-Renewable Resources (PENRR) page. Source: own illustration, SyD-ProBio

ALL POLICY OPTIONS:

SyD-ProBio model users can have access to all of the policy options (some of which are available in different simulation lab pages) through various types of devices (e.g. pie-charts, on-off buttons, graphical/numeric inputs, switch buttons, sliders etc.) presented in the ALL POLICY OPTIONS page (Figure 32). The model users can modify the key assumptions of the default scenarios and run the simulations under the new conditions to test their own policy mixes. To this end, SyD-ProBio enables policy-makers to assess the impact of any policy option from the chosen policy mix on the market uptake of PLA during the next 30 years. By the end of each simulation, the model users can restore all parameters to the default values simply by clicking the “Reset to Default Scenario and Assumptions” button on the upper right corner of this page.

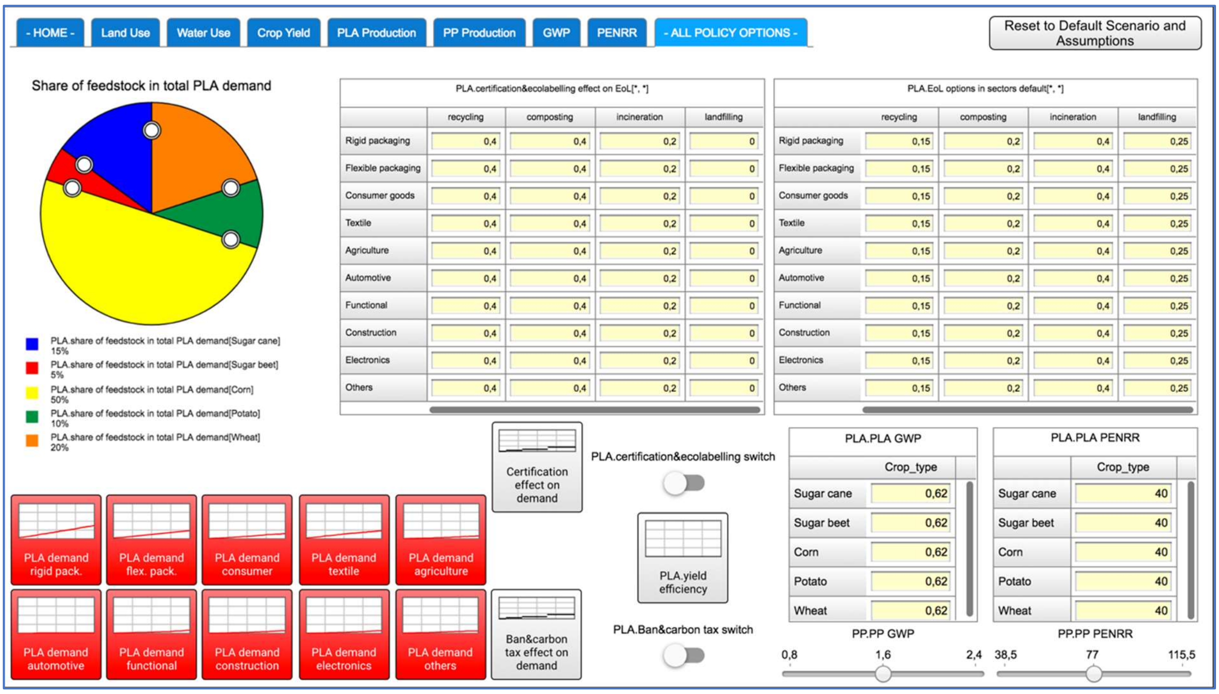

Figure 32: SyD-ProBio Model Simulation Lab – ALL POLICY OPTIONSpage. Source: own illustration, SyD-ProBio

3.2 Scenario comparison, key modelling indicators discussion

This section presents SyD-ProBio model results from two scenario simulations (business as usual – BAU, and alternative future – ALT) in order to demonstrate the potential of the model as a decision support tool for assessing the key dynamics and conditions in the complex bio-based polymer sector from various aspects. Table 5 presents the main model results for the two scenarios comparing the 2020, 2035 and 2050 values of key parameters.

For both of the scenarios, demand for PLA production from 10 different sectors assumed to be linearly increasing based on the market data observed since 2017 and the projections for 2023 (EUBP, 2019) Individual sectors' share in the total PLA demand is also calculated based on this market data. The share of crops used as feedstock in PLA production is assumed to be 15%, 5%, 50%, 10% and 20% for sugar cane, sugar beet, corn, potato and wheat respectively.

Table 5: Modelling results for key parameters for the business as usual (BAU) and the alternative (ALT) scenario. Source: own illustration

Parameter	Unit	BUA Scenario			ALT Scenario		
		2020	2035	2050	2020	2035	2050
Total crop production	t	764.126	2.852.142	5.012.377	3.457.144	9.074.533	24.987.390
Total Land Use for crop production	ha	72.044	268.908	472.581	325.949	855.573	2.355.882
Total water use of crop production	m3	526.725.581	1.966.032.857	3.455.121.535	2.383.071.390	6.255.238.318	17.224.256.359
Total PLA production	t	153.285	572.145	1.005.492	693.509	1.820.368	5.012.515
Total recycled PLA	t	11.715	65.855	133.008	31.240	599.868	1.708.219
PP production	t	10.876.701	16.612.214	25.767.180	10.336.477	15.363.992	21.760.156
PP replaced by PLA	t	153.285	572.145	1.005.492	693.509	1.820.368	5.012.515
Total GWP of PLA production	t CO2 eq	95.037	354.730	623.405	429.976	1.128.628	3.107.760
GWP of PP production	t CO2 eq	17.402.722	26.579.543	41.227.488	16.538.363	24.582.387	34.816.250
GWP saving from substitution of PP with PLA	t CO2 eq	150.219	560.702	985.382	679.639	1.783.960	4.912.265
GWP for PP replaced by PLA	t CO2 eq	245.256	915.432	1.608.787	1.109.615	2.912.588	8.020.025
Total PENRR use of PLA production	GJ	6.139.064	22.914.403	40.269.951	27.775.048	72.905.724	200.751.245
PENRR use of PP production	GJ	837.506.003	1.279.140.512	1.984.072.860	795.908.731	1.183.027.359	1.675.532.043

The effects of a substitution of fossil-based PP with bio-based PLA are simulated, with PLA market shares for the BAU scenario up to 4% and for the ALT scenario up to 19% (in 2050). Global warming potential savings can be expected based on the currently calculated technology mix to improve 5-fold in the ALT-scenario compared to no extra bio-based polymers relevant policies being taken (BAU-scenario). Crops dedicated for this novel materials sector increase to 5 million tonnes and 25 million tonnes respectively with primary biomass input mainly from sugar cane (34%), followed by corn (20%), potato (19%), wheat (14%) and sugar beet (9%) respectively. This results in total land use of up to 500.000 ha and 2,3 million ha in the two scenarios respectively and water use of up to 1,7*10^{10} m^3.

Graphical representations of these key model parameters are presented and discussed in the following sections below.

3.2.1 Results of land use, water use and crop yield under BAU and ALT scenarios

Figure 33 and Figure 34 show land use change under BAU and ALT scenarios respectively.

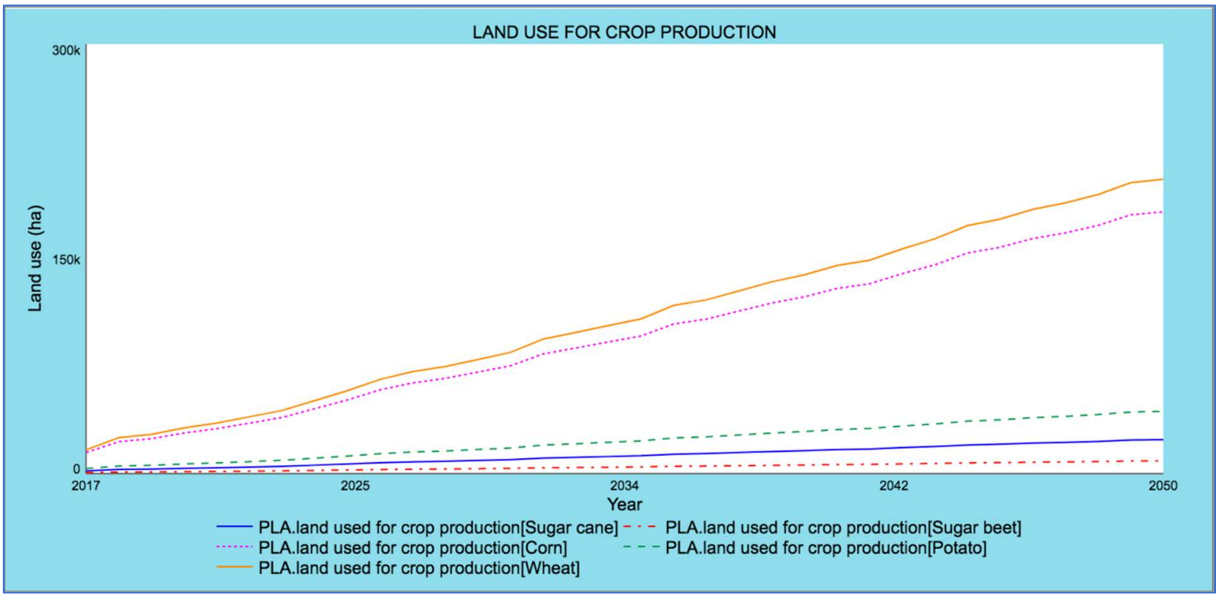

Figure 33: Land use (ha) for crop production under BAU scenario. Source: own illustration produced in SyD-ProBio

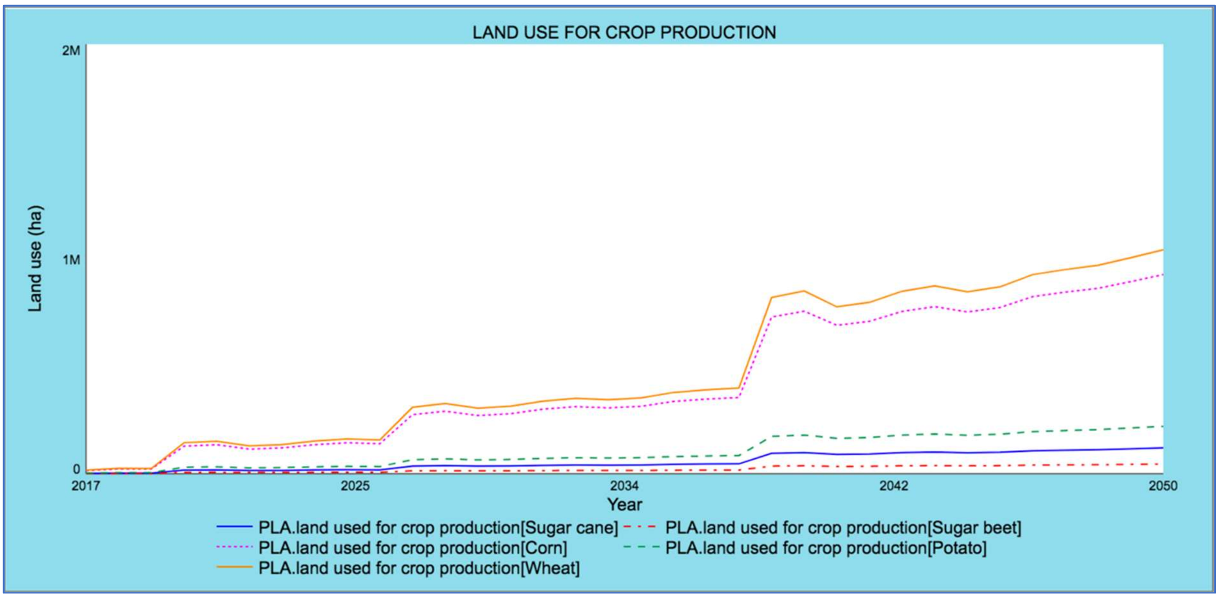

Figure 34: Land use (ha) for crop production under BAU scenario. Source: own illustration produced in SyD-ProBio

The drastic increase in land use in the ALT scenario is due to two reasons:

1) A future ban and/or carbon tax is implemented on PP production with a graph function as shown in Figure 35. (5% reduction between 2020-2026, 10% between 2027-2037, and 20% between 2038-2050). This leads to a substitution of PP with PLA, increasing the demand for raw material for PLA production and hence the land use.
2) A future sustainability certification and/or ecolabelling is implemented for PLA (or bioproducts in general) with a graph function as shown in Figure 35. This leads to an increase in the demand for PLA (5% increase between 2020-2026, 10% between 2027-2037, and 20% between 2038-2050).

Figure 35: Left: Ban and/or carbon tax implementation on PP with a graphical device in the user interface. The graph shows the reduction in PP demand. Right: Certification and/or ecolabelling implementation on PLA with a graphical device in the user interface. The graph shows the increase in PLA demand. Source: own illustration produced in SyD-ProBio

In order to illustrate the effect of these two policy implementation, we run the SyD-ProBio model by switching on and off the “ban and/or carbon tax” and “Certification and/or ecolabelling” implementations one at a time. Figure 36 shows the effect of only “ban and/or carbon tax” (on PP) policy implementation on land use, whereas Figure 37 shows the effect of only "Certification and/or ecolabelling" (on PLA) policy. It can be shown based on these two figures that the "ban and/or carbon tax" policy implementation on PP has a much higher impact on the land use because of the higher volumes of PLA produced in order to substitute the PP.

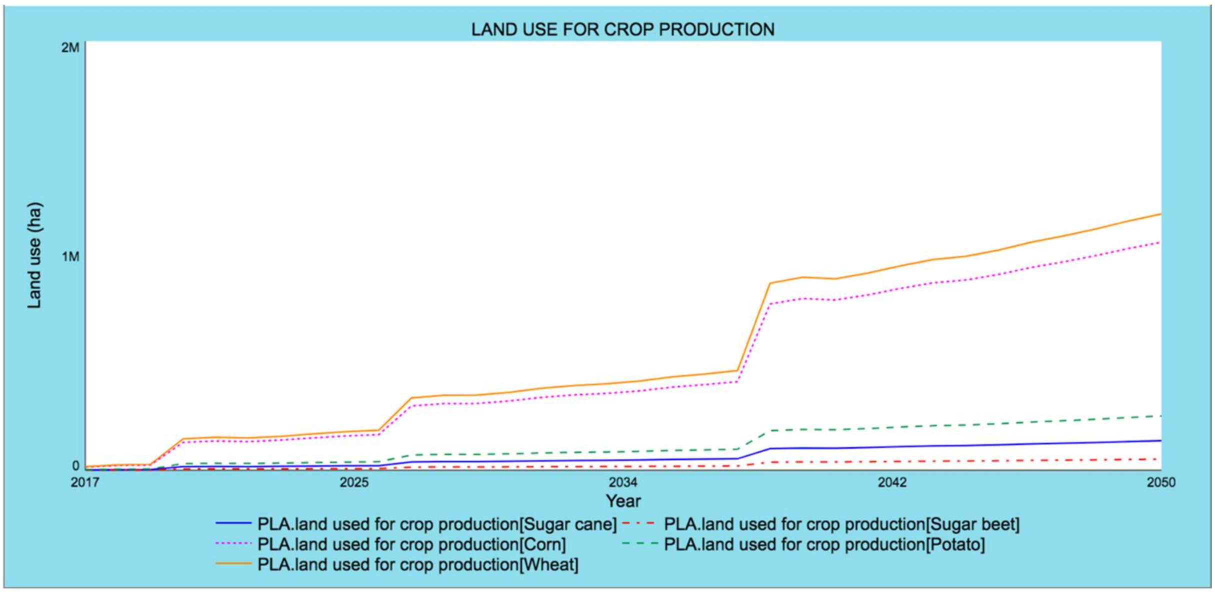

Figure 36: Land use (ha) for crop production under ALT scenario – only "ban and/or carbon tax" policy implemented. Source: own illustration produced in SyD-ProBio

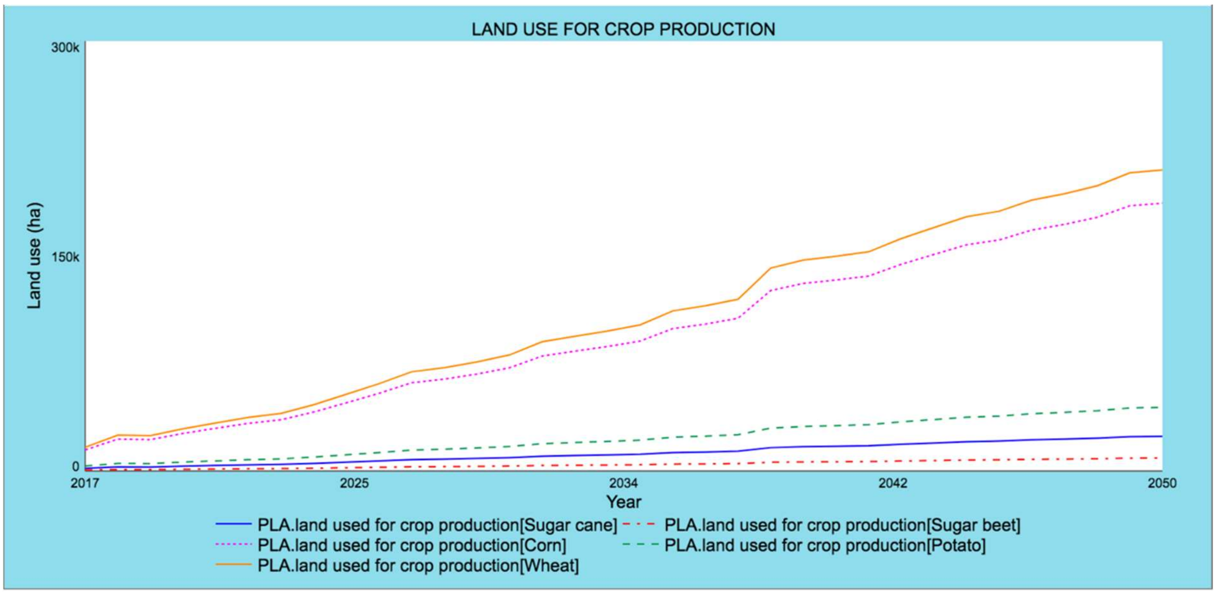

Figure 37: Land use (ha) for crop production under ALT scenario – only "Certification and/or ecolabelling" policy implemented. Source: own illustration produced in SyD-ProBio

The results of water use and crop yield show same changing trends as the modelled land use results under the BAU and ALT scenarios (Figure 38 - Figure 41).

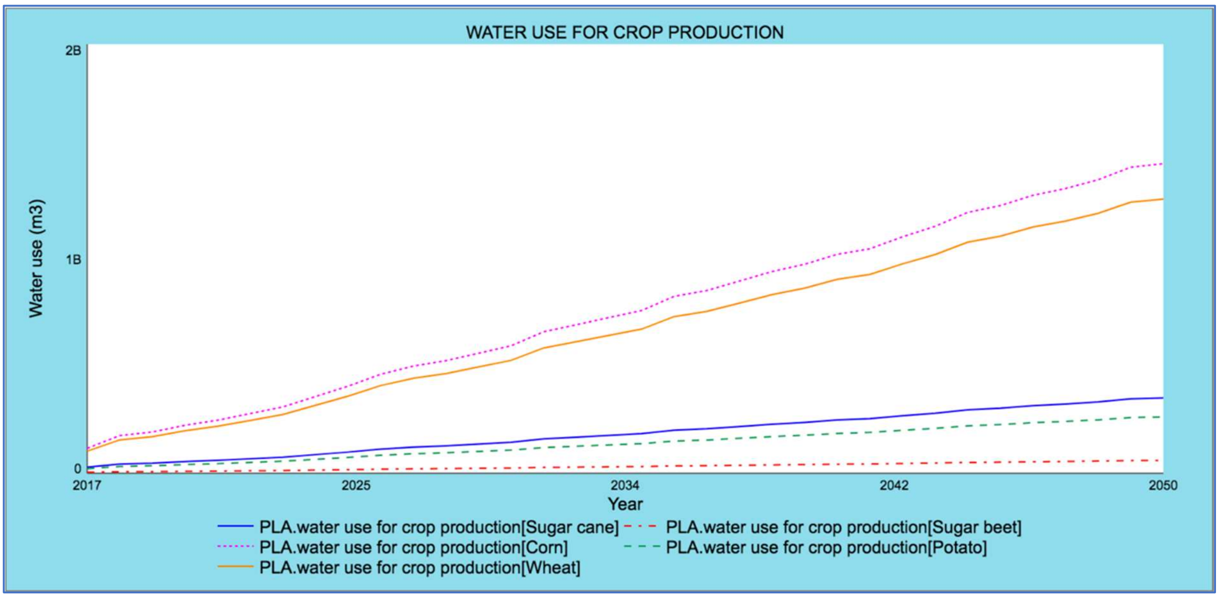

Figure 38: Water use (ha) for crop production under BAU scenario.

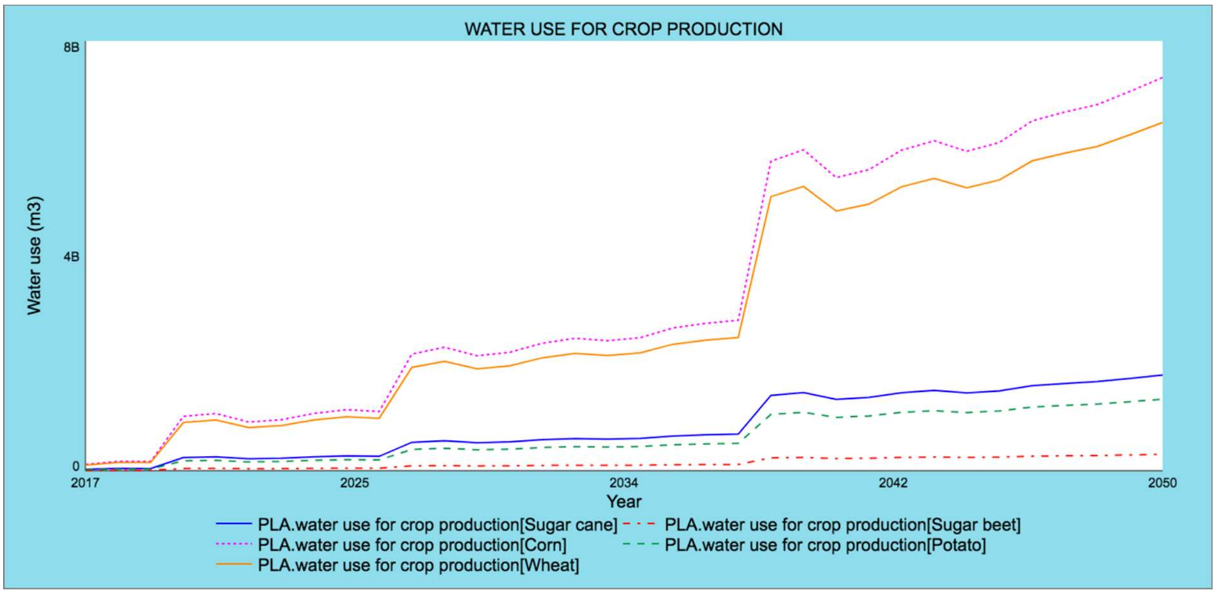

Figure 39: Water use (ha) for crop production under ALT scenario.

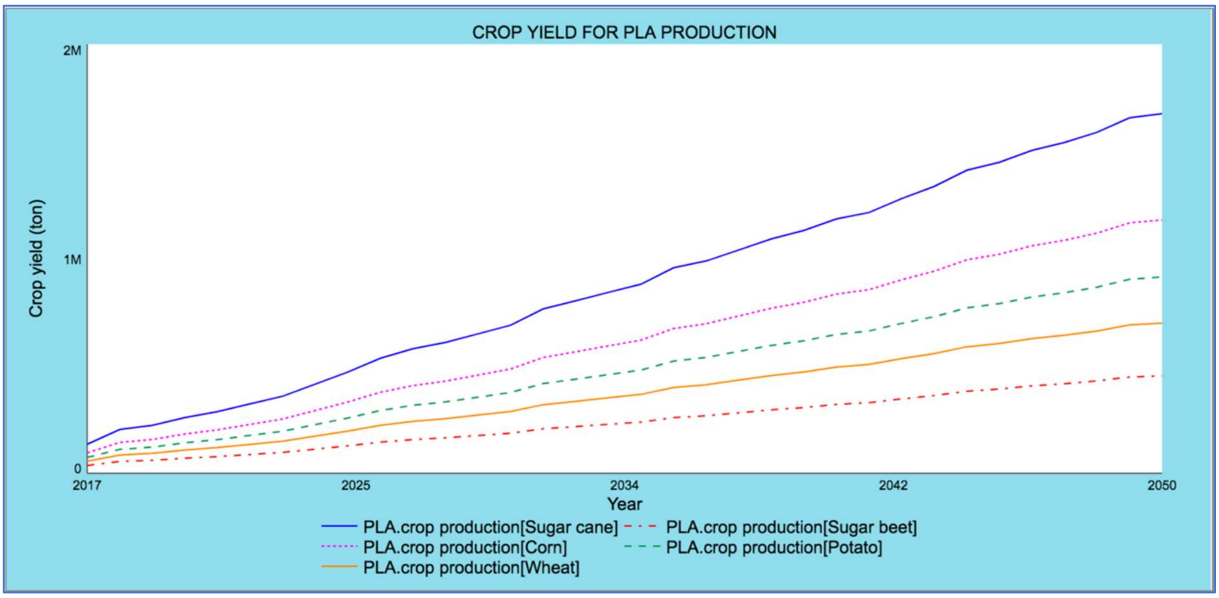

Figure 40: Crop yield (ton) under BAU scenario.

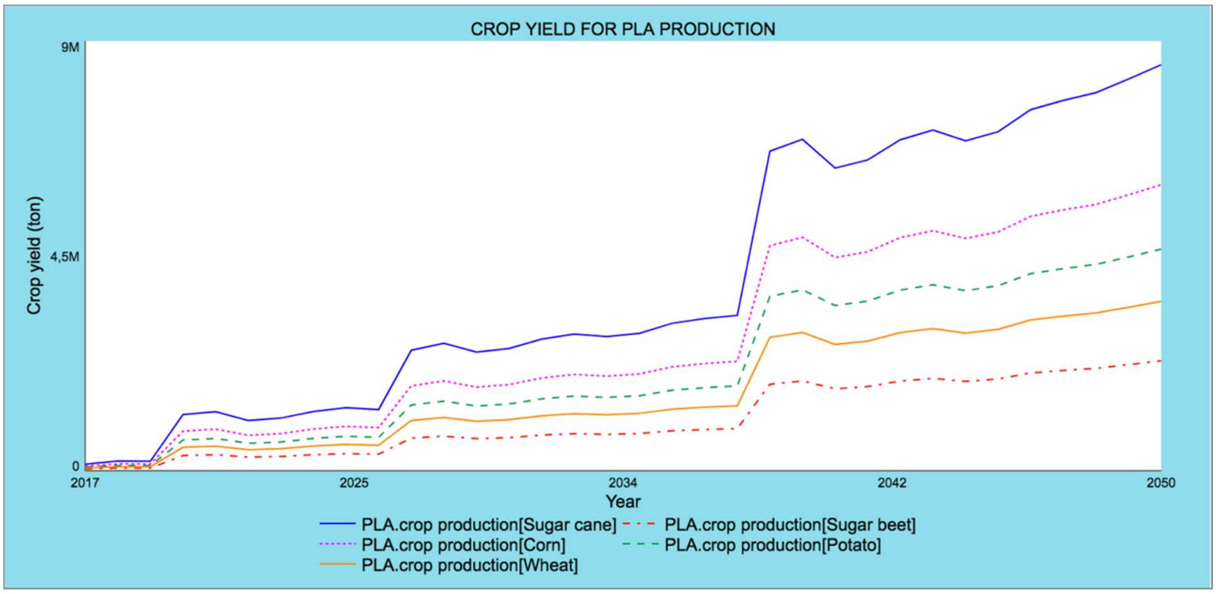

Figure 41: Crop yield (ton) under ALT scenario.

3.2.2 Results of PLA Production and Recycling substituting PP production under BAU and ALT scenarios

The results of PLA production and recycling under BAU and ALT scenarios are presented in Figure 42 - Figure 45. The implementation of the ban and/or carbon tax on PP production under ALT scenario leads to a substitution of PP with PLA (Figure 46 and Figure 47), increasing the PLA production. Similarly, implementation of the sustainability certification and/or ecolabelling for PLA under ALT scenario leads to an increase both in the demand for PLA (and in turn PLA production) and in the recycling of PLA.

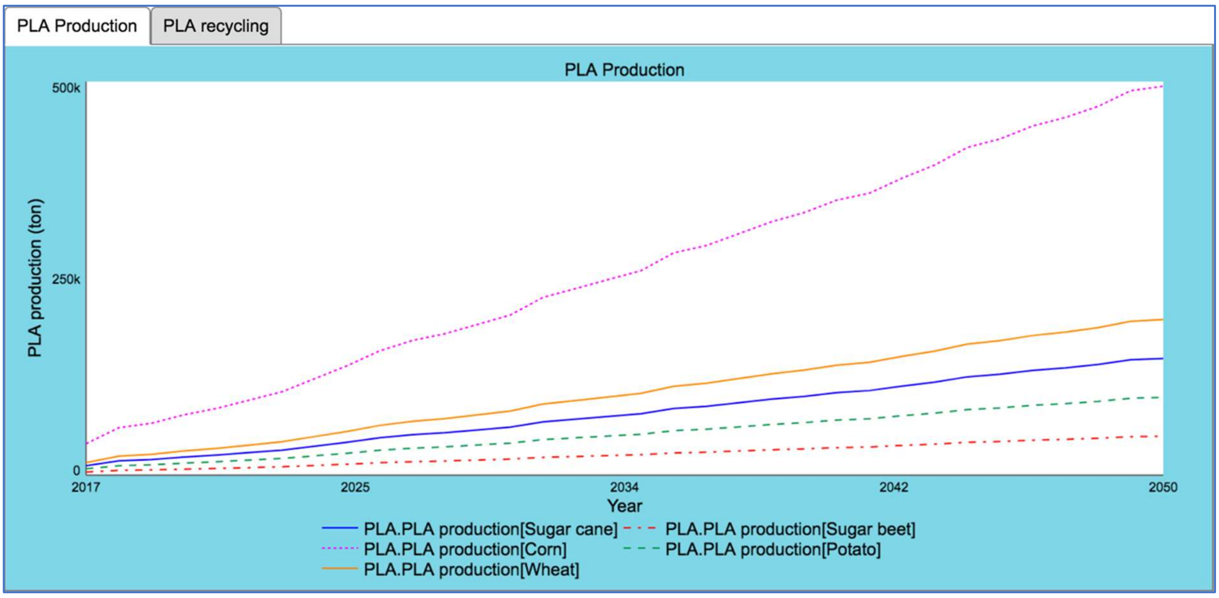

Figure 42: PLA production (ton) under BAU scenario.

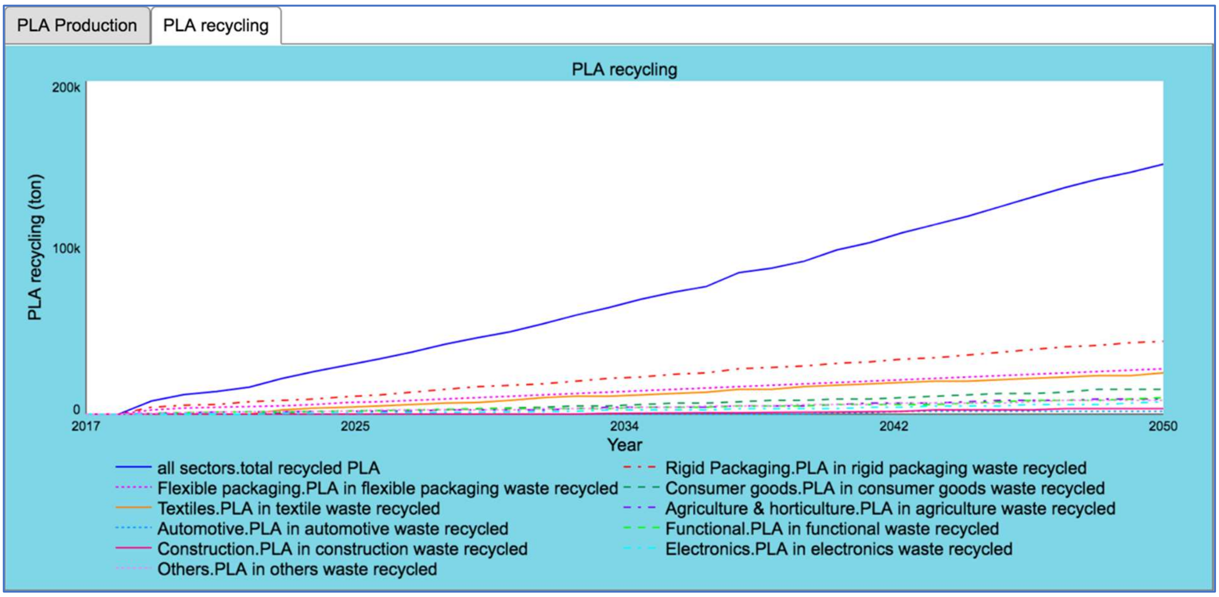

Figure 43: PLA recycling (ton) under BAU scenario.

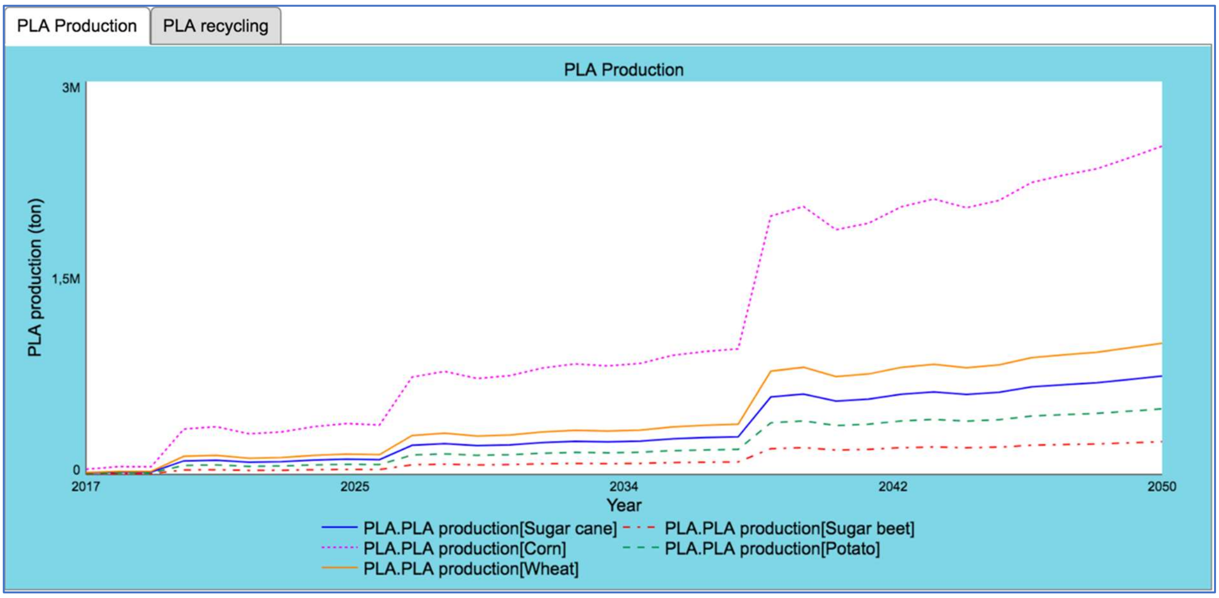

Figure 44: PLA production (ton) under ALT scenario.

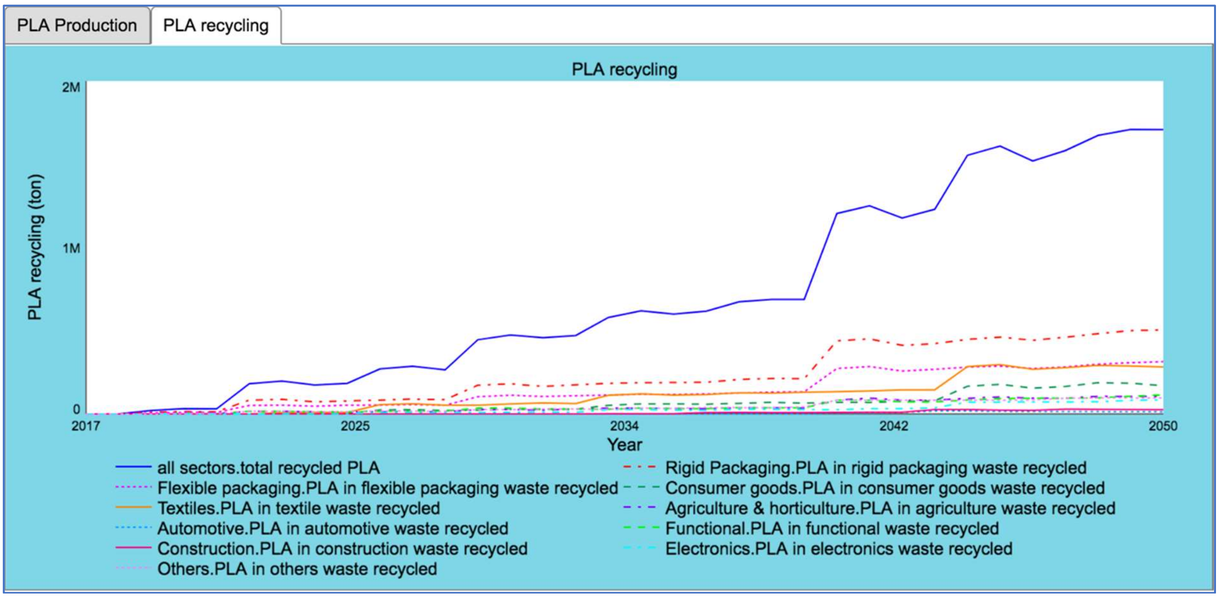

Figure 45: PLA recycling (ton) under ALT scenario.

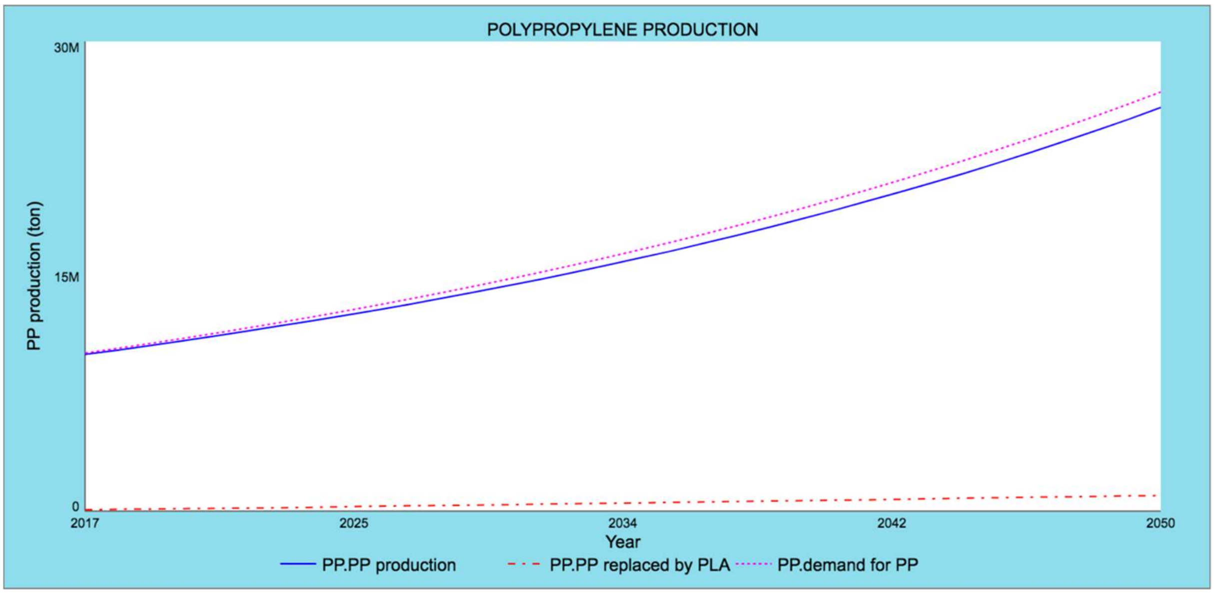

Figure 46: PP production (ton) under BAU scenario.

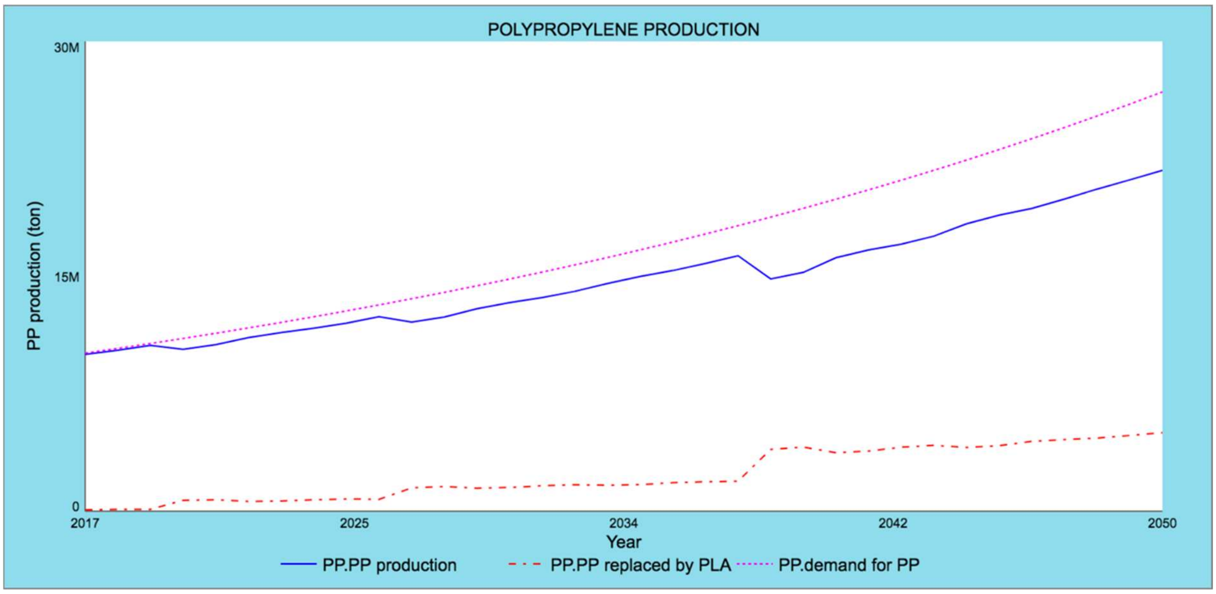

Figure 47: PP production (ton) under ALT scenario.

3.2.3 Results of Global Warming Potential (GWP) of PLA and PP under BAU and ALT scenarios

The results of GWP of PLA and PP, as well as GWP reductions due to substitution of PP by PLA under BAU and ALT scenarios are presented in Figure 48 – Figure 51.

In the BAU scenario, GWP of PP production is much higher as compared to GWP of PLA production (Figure 48). There is some amount of GWP savings due to substitution effect (Figure 49), but it is negligible if compared to the total amount of GWP of PP production.

In the ALT scenario, with the substitution of PP with PLA due to the ban and/or carbon tax implemented on PP production, there is a considerable amount of reduction in the GWP of PP production. Even though the sustainability certification and/or ecolabelling implementation for PLA leads to an increase in the demand for PLA and thus increase the market uptake of PLA against PP, this policy option alone does not have much effect on the GWP of PP production.

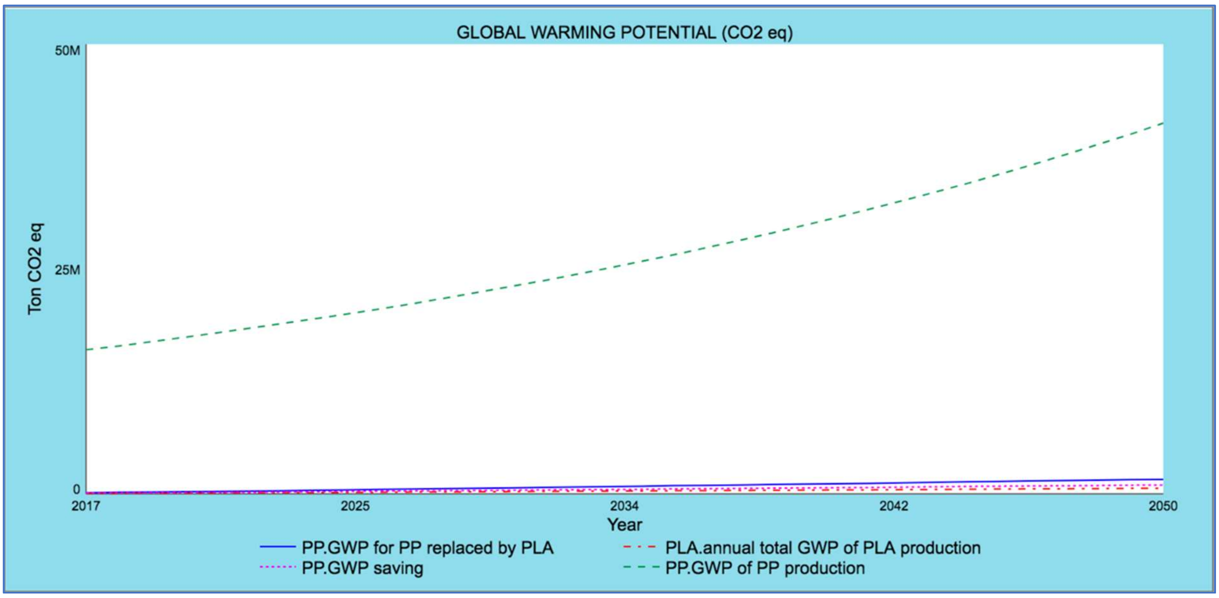

Figure 48: Global Warming Potential of PP and PLA (ton CO_2 equ.) under BAU scenario.

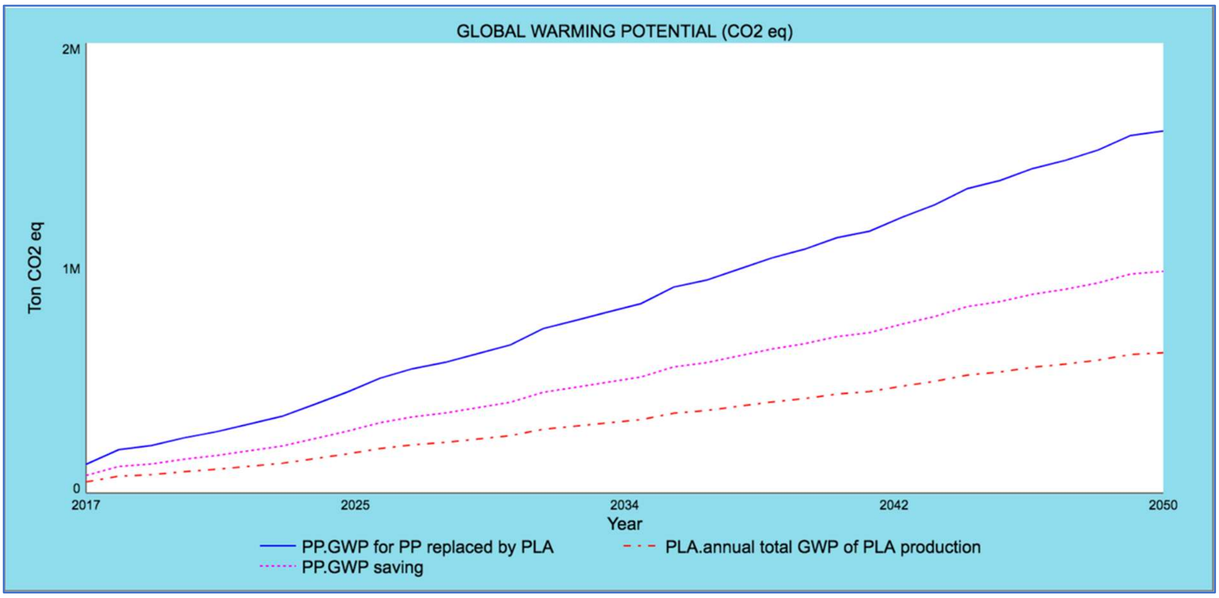

Figure 49: Global Warming Potential savings by substituting PP with PLA (ton CO_2 equ.) under BAU scenario.

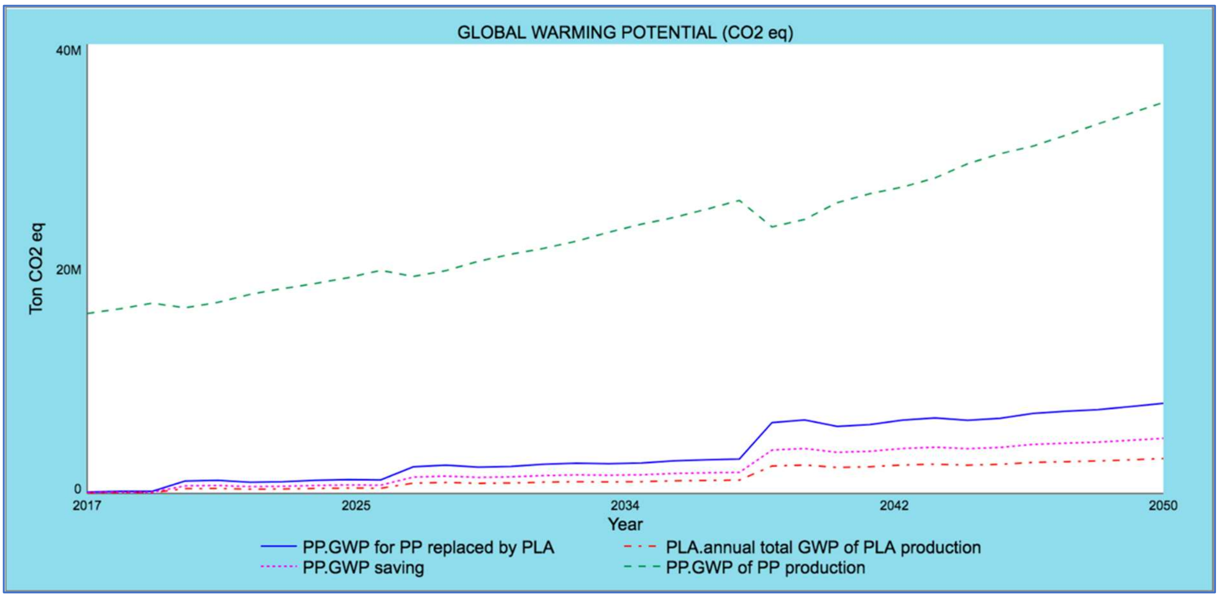

Figure 50: Global Warming Potential of PP and PLA (ton CO_2 equ.) under ALT scenario.

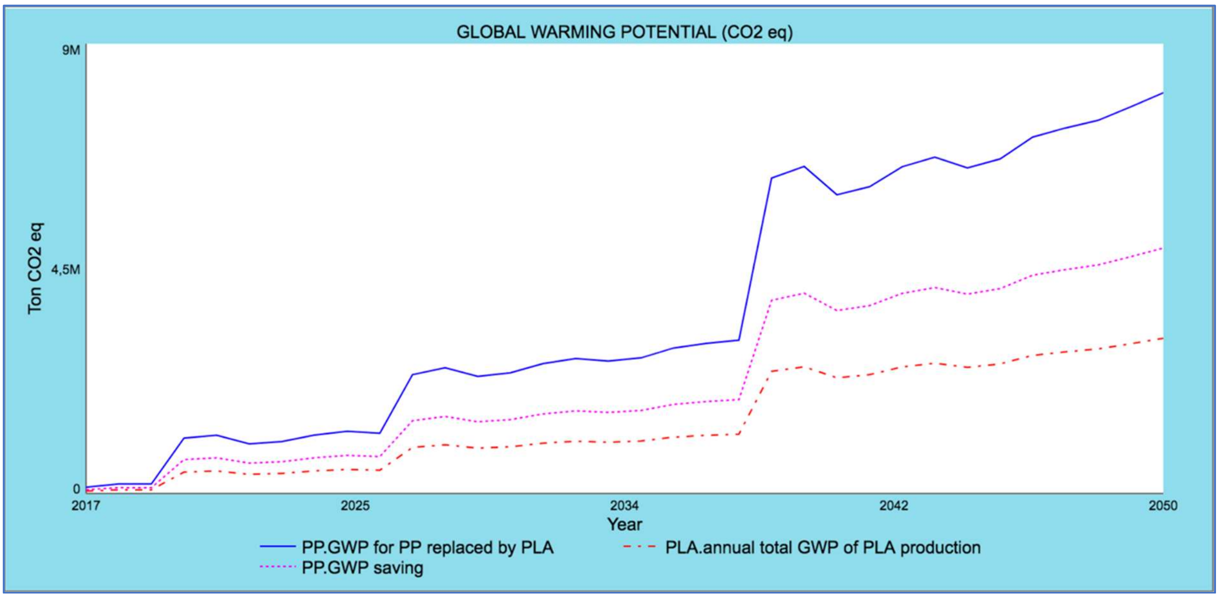

Figure 51: Global Warming Potential savings by substituting PP with PLA (ton CO_2 equ.) under ALT scenario.

3.2.4 Results of Primary Energy from Non-Renewable Resources (PENRR) under BAU and ALT scenarios

The results of PENRR use for PLA and PP production under BAU and ALT scenarios are presented in Figure 52 - Figure 55.

In the BAU scenario, PENRR use for PP production is much higher as compared to PENRR use for PLA production (Figure 52). There is some amount of savings in the use of PENRR due to substitution effect (Figure 53), but it is negligible if compared to the total amount of use of PENRR for PP production.

In the ALT scenario, with the substitution of PP with PLA due to the ban and/or carbon tax implemented on PP production, there is a considerable amount of reduction in the use of PENRR for PP production (Figure 54 & Figure 55). Even though the sustainability certification and/or ecolabelling implementation for PLA leads to an increase in the demand for PLA and thus increase the market uptake of PLA against PP, this policy option alone does not have much effect on the use of PENRR for

PP production.

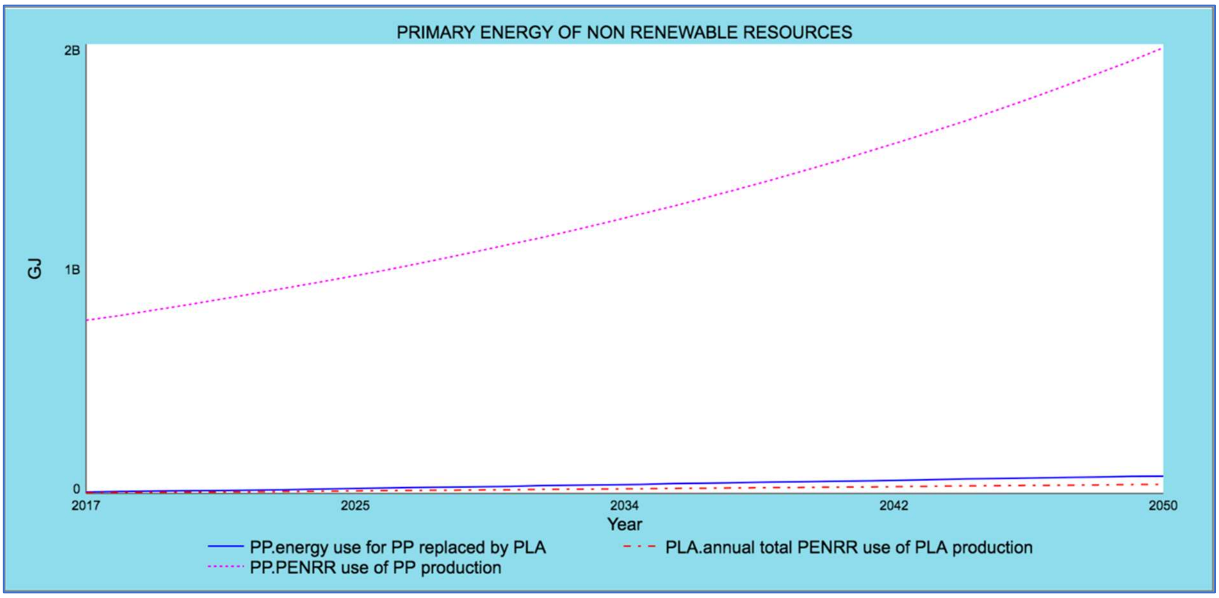

Figure 52: PENRR use for PP and PLA production (GJ) under BAU scenario. Source: own illustration produced in SyD-ProBio

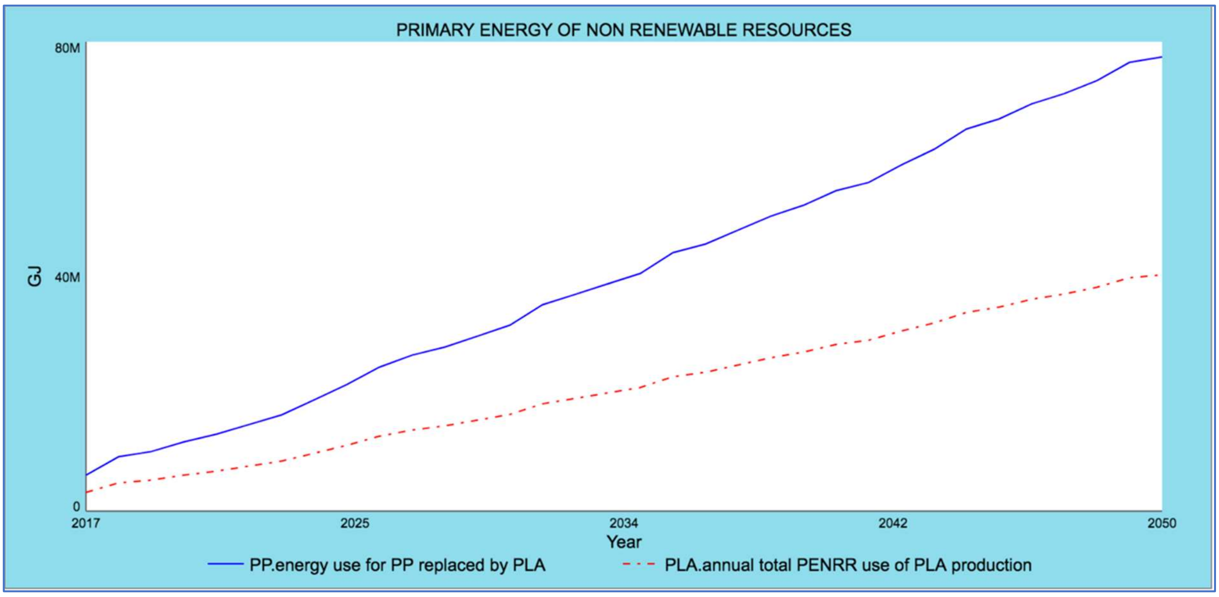

Figure 53: Savings in the use of PENRR by substituting PP with PLA (GJ) under BAU scenario. Source: own illustration produced in SyD-ProBio

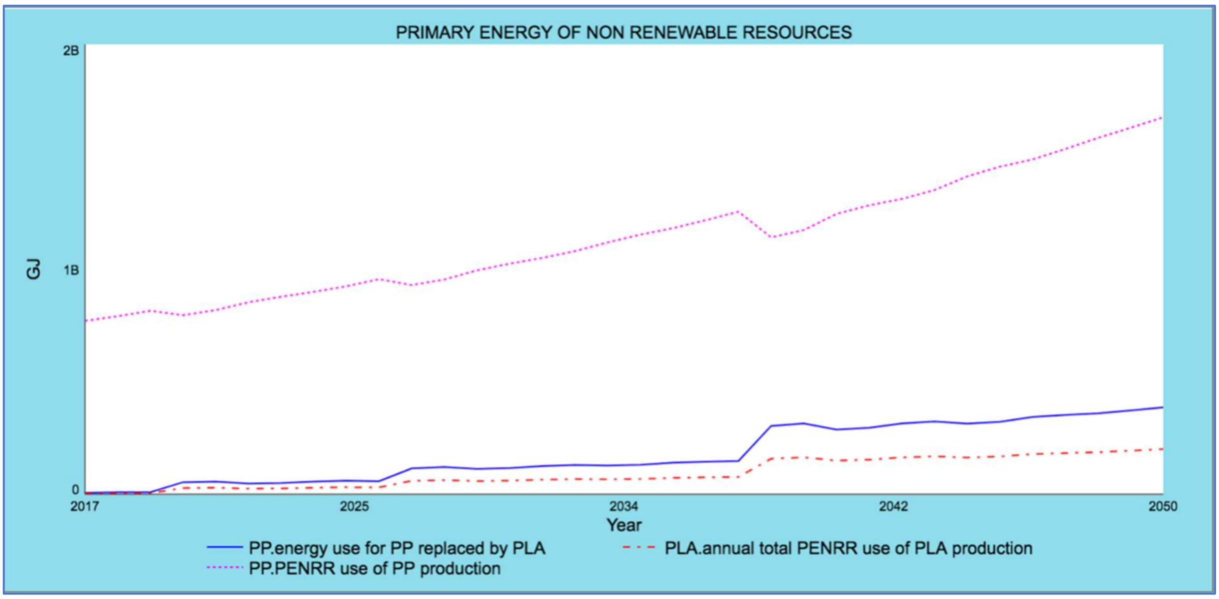

Figure 54: PENRR use for PP and PLA production (GJ) under ALT scenario. Source: own illustration produced in SyD-ProBio

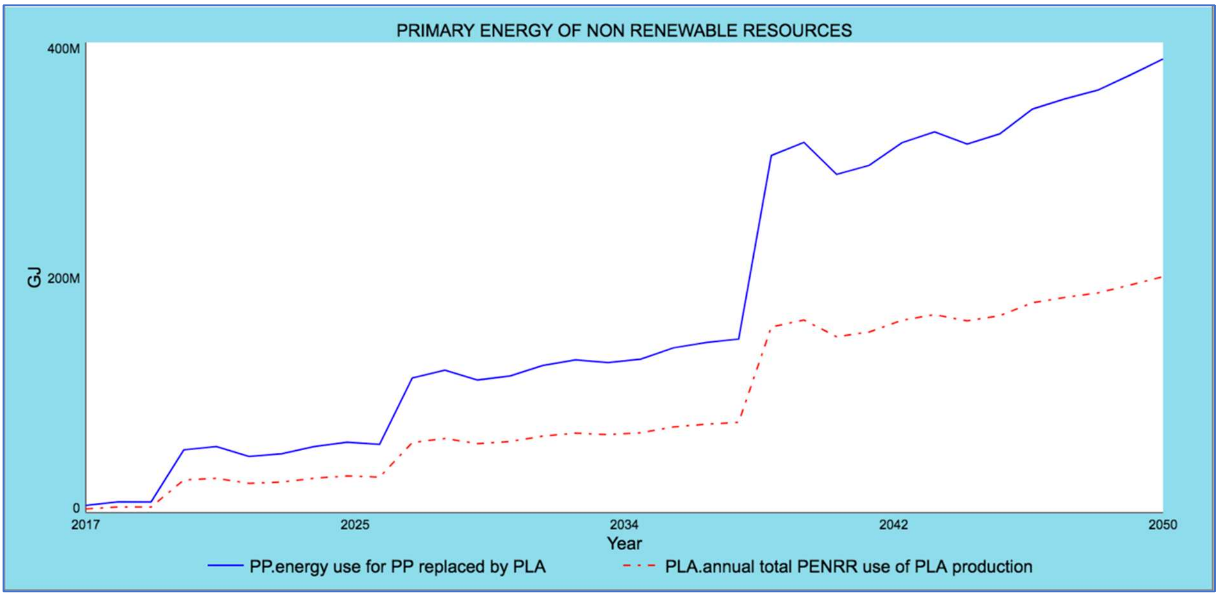

Figure 55: Savings in the use of PENRR by substituting PP with PLA (GJ) under ALT scenario. Source: own illustration produced in SyD-ProBio

4. DISCUSSIONS, RECOMMENDATIONS AND CONCLUSIONS

4.1 Designing policies for a level playing field

In this deliverable, we have presented SyD-ProBio system dynamics model as a tool for policy assessment. With model simulations we have tested and discussed the dynamics of different types of policy interventions on the market diffusion of advanced bio-based materials i.e. sustainable PLA. Main levers have been identified based on the discussed narratives and their most sensitive dynamics:

1. Phasing-out of conventional, fossil-based plastic consumption
2. Increasing bio-based polymers production and market uptake
3. Ensuring environmental sustainability and the continuous improvement of other sustainability parameters of bio-based polymers throughout the life-cycle (primary feedstock sourcing, production process, consumption)
4. Improving the circularity of bio-based polymers at the end-of-life of the products life-cycle

Actively steering these dynamics is clearly a multi-level governance problem:
While the willingness to pay of individuals and public procurers can be influenced to a certain extent, actual costs of bio-based products and cost differences to their traditional, fossil-based counterparts play a decisive role. Thus, commodity price developments of e.g. crude oil and biogenic carbon carriers (biomass) and their level of price integration will remain critical factors. De-coupling primary sourcing for bio-based chemicals production, namely de-coupling the production, harvesting, preparation and supply of raw biomass from fossil fuels inputs can be recommended in order to not only improve the product environmental footprints but also to protect them from oil price fluctuations.

Another macro-level factor group includes the development of financial, human as well as information capacities for the transformational change from a fossil based, towards a circular bio-based economy. Investment & divestment frameworks (e.g. sustainable taxonomy), poverty eradication, development cooperation, capacity building as well as globally improving our ability to measure, monitor, access and share data and information relevant for this transformation will prove essential. Bi-lateral partnerships (e.g. the Africa-Europe Alliance) but especially also international and multi-lateral organizations such as the United Nations (UN) or the Organization for Economic Development and Cooperation (OECD) and their topic specific transnational networks (e.g. the Global Plastic Alliance) play an important role in setting global agendas and organizing and distributing financial, human and information capacities. The role of stakeholder associations has to be considered as well as the role of non-governmental organizations (NGOs), transnational companies, communities, sub-national and grassroot activities. For example, companies such as LEGO, IKEA or McDonald pledge targets for improving the sustainability of the plastic content of their products for a given time-frame (OECD, 2019). European Bioplastics (EUBP) represents individual firms and lobbies on European and national governmental level for the market uptake of respective products while NGOs can raise awareness for safety and sustainability issues. Community recycling initiatives help overcoming regulatory gaps and grassroot activities especially contribute to the diffusion of social innovations such as product sharing or food-waste avoidance activities.

However, this work and report focuses on the European governmental level, with the bulk of policy relevant documents analyzed stemming from the European Commission, their contracting parties or decisions from the European Parliament and the European Council. The strongest barrier on a European level regarding the four identified dynamics can be seen in the fact, that the Union does not have the mandate to regulate a single integrated market for the discussed products. Thus, EU-wide unified taxes for fossil carbon-based materials, quotas or incentives for bio-based materials are unlikely since they would depend on the harmonization of MS-level ordinances based on EU directives. On the other hand, the Unions track-record in setting common frames and goals is improving, which are in return pursued by a high diversity of more or less ambitious and effective national ordinances, streamlined to the national policy settings. Furthermore, sub-national, regional and urban governance create and test another dimension of diversity of measures that should be considered for implementation on higher levels when proven effective. Still, and as already outlined in the STAR-ProBio project D9.1, improved coherence in progressing towards sustainability targets between the different policies on the various levels but also between the different policy frameworks of the EU is key to avoid spillage effects and harness possible synergies. Additional major efforts in consolidating and, if necessary and possible, harmonizing policies have to be actuated in the policy arena but also in the realms of systemic-transdisciplinary science (Schinko et al., 2017).

Based on the existing EU policy documents and expected communications (both listed in Table 6 and Table 7 in Annex) we identify the main policy agendas that provide opportunities for steering the outlined dynamics on a European level. Main key actions are sourced from the Green Deal (EC, 2019) and the new Circular Economy Action Plan (EC, 2020) and listed and described here in the following, respective quotation marks refer to these sources.

For 2020 a legislative proposal on substantiating green claims is scheduled. The basis for claims is the Product and Organisation Environmental Footprints to be tested on the EU Ecolabel. STAR-ProBio project results on labelling will be ready to be communicated and directed towards respective channels. This could be an important step in improving coherency of policies across a large set of sectors. Furthermore, and in relation to this first point, the Commission is going to propose a revision of consumer laws to protect consumers against green washing and to set "minimum requirements for sustainability labels/logos and for information tools". On a global level and more product specific, a global agreement on plastics will be followed up mainly focusing on limiting plastic pollution and with regard to achieving climate-neutrality by 2050 long-term strategies are to be submitted by the Commission and each MS to the United Nations Framework Convention on Climate Change. Not relevant for the current bio-based polymers supply chains now, but potentially relevant in the mid-term future are measures discussed to counter deforestation. Sustainable wood and wood residues supply will be decisive for extending the feedstock portfolio beyond agricultural products and residues.

In 2021 a policy framework for bio-based plastics and biodegradable or compostable plastics is scheduled. Applications will be identified and defined, where the use of bio-based polymers can result in environmental benefits and where and how to implement biodegradable and compostable plastics going again hand in hand with regulating respective labelling. Also, "a legislative initiative on reuse to substitute single-use packaging, tableware and cutlery by reusable products in food services" could impact on fossil-based chemicals demand or even on bio-based polymers production if the scope of this initiative can be extended. Similarly, restrictions and measures against microplastics can be expected. Also, the review "to reinforce the essential requirements for packaging and reduce (over)packaging and packaging waste" should be supported with insights from the STAR-ProBio project. A legislative proposal for an initiative on sustainable product policies will again address the EU Ecolabel in 2021, but first and foremost also propose "minimum mandatory green public procurement (GPP) criteria and targets in sectoral legislation". Non-energy related products will be incorporated into the Ecodesign framework. The configuration of this initiative will be decisive for the market uptake of increasingly sustainable bio-based polymers. With regard to data and information capacities, the update of the Circular Economy Monitoring Framework including novel indicators on resource use, as well as consumption and material footprints is going to reflect the new policy priorities. Primary sourcing of feedstock and energy for the production process will likely to be influenced on a medium term by the content of the proposals for revising the Emissions Trading System, and regulations and directives on land use, land use change and forestry, energy efficiency and renewable energy. Furthermore, also emission targets from large industrial installations will be further strengthened and carbon border adjustment mechanism for selected sectors will be proposed to address the risk of carbon leakage.

In 2022, 2023 or still with an open schedule the following developments will impact on the dynamics in question: An initiative on a possible EU wide harmonized model for the separate collection of waste and its labelling will be launched addressing "the most effective combinations of separate collection models". With regard to specific products potentially based on bio-based polymers, also textile wastes will have to be collected separately and additional requirements can be expected for construction products. In order to reduce the dependence on bottled water, the public accessibility of drinkable tap water is going to be more strictly monitored and supported. Main influential policies and frameworks for primary sourcing of feedstocks will be the revised Common Agricultural Policy but also a "regulatory framework for the certification of carbon removals", which will be based on "robust and transparent carbon accounting to monitor and verify the authenticity of carbon removals". Financial capacities are going to depend on the development of the EU Taxonomy framework and respective sustainable investment plans.

Further upcoming European strategies, that have to be monitored with regard to the discussed dynamics include the 2030 Biodiversity strategy and the forest strategy, the Chemicals Strategy for Sustainability, the Strategy for Plastics in the Circular Economy and the EU Strategy for textiles. More indirect impacting policy and framework developments, which are expected to be most difficult to measure or to integrate into the SyD-ProBio model include for example a skills agenda, cohesion policy and cohesion and social policy funds, a just transition mechanism and developments with regard to the overall governance within the European Union. Respective measures can have a strong influence on the discussed dynamics too, even though they are barely discussed in this deliverable.

Clearly, simulated BUA and ALT scenarios in this deliverable are only two of many other potential "what if" type of explorative scenarios. The "Simulation Lab" in the SyD-ProBio model user interface allows the model users to develop and test a wide range of policy options affecting the market uptake of PLA in Europe. Policy options implemented so far and ready for testing include e.g. (1) increased yield and water efficiencies, (2) different GWP and PENRR use of PP and PLA with improvements in the production processes, (3) sectoral policies affecting the sectoral demand for PLA, (4) agricultural policies affecting the share of crops used in PLA production, and (5) other policies affecting the demand and production of PLA and PP in general (i.e. public procurement, public awareness campaigns etc.).

4.2 Next steps

The underlying work for this deliverable should be seen as a starting point, delivering solid ground work with (1) a quantitative model that allows for easy further integration of modules; (2) a graphical user interface (GUI) that can be implemented as an online tool and further optimised to serve the needs of various groups from academia, NGOs, policy makers and other stakeholders; and (3) an innovatively structured database of existing and upcoming relevant policy documents and policy measures/options.

Next steps for the (1) SyD-ProBio model development will be the integration of further bio-economy sectors e.g. competing bioenergy deployment pathways, future biogenic carbon supplying technologies based on novel primary feedstocks such as biomass gasification of ligno-cellulosic biomass, as well as further refining of already implemented feedstocks depending on production, harvesting and processing methodologies and conditions. Furthermore, the integration of renewable energy deployment for the polymers production process has to be considered along with some other key policy measures and options outlined in this deliverable. Based on the primary example of PLA-production, further interesting bio-based polymers such as PHA, PBS and starch blends should be considered for the extension of the SyD-ProBio model's functionalities.

To be able to perform comparative analysis across the considered scenarios, we have defined a set of results indicators e.g. global warming potential, primary energy from non-renewable resources, land use, water use, carbon taxation etc. Due to time constraints and scarcity of data, in the current version of the SyD-ProBio model we have implemented only limited number of such indicators (mostly belonging to the environmental and economic pillar). More indicators, especially from other pillars of sustainability (e.g. social –number of jobs created) will be considered during the future model development work.

For one of the main novelties of this deliverable, namely the (2) easy-to-handle and understandable graphical user interface (GUI), an online implementation on the STAR-ProBio project's homepage is considered. Through further scenario testing and utilization of the GUI and, valuable experience and insights will be gathered leading to further model development and GUI design. Only through analyzing, how different types of interested users are utilizing this tool we will be able to plan the next versions for unleashing the full potential of the presented version of the model. This includes back-end development to collect user data in a GDPR-conform way, usability engineering, optimization of training materials including videos and workshops, maintenance and performance engineering.

The (3) presented policy database and policy clustering and analysis methodology for bio-based products offers a broad range of research and development opportunities itself: On the one hand, the developments based on the very few policy measures and options existing, for which a direct quantifiable impact can be modelled need to be monitored and the impact on different types of bio-based polymers developments verified. On the other hand, each non-quantifiable policy measure can be and is partly found as an individual research topic on its own, e.g. by trying to derive statistically significant macro-economic effects, which could further again be implemented into the SyD-ProBio model or other modelling efforts. The power play of different groups in the policy arena needs to be discussed, based on a throughout stakeholder and interest mapping to provide a scientific representation of which levers can actually be moved and what resources would have to be committed e.g. in terms of classical lobbying work or through public campaigning. Furthermore, governance and governance structures are of the essence and policy analysis and modelling would benefit of a higher resolution by further including developments on the member state level as well as including global developments and further details of respective complex topics such as trade and negotiations on climate change mitigation and adaptation action. Finally, and as also revealed in the STAR-ProBio project Deliverable 9.1 and underpinned with new insights and data within this project, with regard to policy coherence we are just in the very beginning and major scientific and political efforts will be needed to avoid e.g. carbon leakage and mitigate impacts of the bioeconomy on indirect land-use chains or even to establish a level-playing field for increasingly sustainable production and consumption throughout all sectors.

Several scientific publications derived from the work conducted in task 9.5, will be published in the next months, covering the model development process aspects in greater details, illustrating the use of SyD-ProBio model for an extended portfolio of bio-based products and/or sectors, testing different policy mixes that could ensure the creation of a level playing field for the market uptake of sustainable bio-based products.

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6. ANNEX

6.1 Screened policy documents

Table 6: Official communications (action plans, directives, regulations, strategies & roadmaps) and their relevance for specific bio-based materials supply chain stages. Source: own compilation

Publication date	Communication Title and Code	Stage(s) of the supply chain covered
May 1991	Urban Wastewater Treatment Directive – 91/271/EEC	A – Primary sourcing
December 1991	Nitrates Directive – 91/676/EEC	A – Primary sourcing
April 1999	Landfill Directive - 1999/31/EC	D – End of Life (EoL)
October 2000	Water Framework Directive – 2000/60/EC	A – Primary sourcing
September 2003	Regulation on additives for use in animal nutrition – (EC) 1831/2003	A – Primary sourcing
March 2004	EU Public Procurement Directives – 2004/18/EC & 2004/17/EC	C – Product
June 2006	Regulation on shipments of waste – (EC) 1013/2006	D – End of Life (EoL)
December 2006	REACH Regulation – (EC) 1907/2006	B – Process; C - Product
January 2008	Feed additives Directive – (EC) 33/2008	A – Primary sourcing
November 2008	Waste Framework Directive - 2008/98/EC	D – EoL;
November 2008	Communication on the raw materials initiative – COM/2008/0699	A – Primary Sourcing, D – End of Life
November 2009	Regulation on the EU Ecolabel – (EC) 66/2010	C - Product
November 2009	Regulation on Cosmetic Products – (EC) 1223/2009	C – Product;
November 2009	European Commission - Taking bio-based from promise to market. Measures to promote the market introduction of innovative bio-based products	B - Process, C - Product
October 2010	Consolidated version of the Treaty on the Functioning of the European Union – OJC 326	E – Cross-cutting
November 2010	Industrial Emissions Directive 2010/75/EU	B - Process
March 2011	Construction products regulation – (EU) 305/2011	C - Product
March 2011	A Roadmap for moving to a competitive low carbon economy in 2050 (COM(2011)112 final)	E – Cross-cutting
September,2011	Roadmap to a Resource Efficient Europe (COM(2011) 571)	E – Cross-cutting
February 2012	Innovating for Sustainable Growth: A Bioeconomy for Europe, DG for Research and Innovation, EC	E – Cross-cutting
May 2012	A Blueprint to Safeguard Europe´s Water Resources (COM/2012/0673)	A – Primary sourcing
April 2013	Communication on building the Single Market for Green Products Facilitating – COM/2013/0196	C – Product;
May 2013	LULUCF Directive – 529/2013/EU	A – Primary sourcing
November 2013	7th Environment action Programme to 2020 (1386/2013/EU)	
December 2013	CAP European Common Agricultural Policy - Regulations (EU) 1305-1308/2013	A – Primary sourcing
October 2014	2030 Climate & Energy framework (COM/2014/015 final)	B-Process,
April 2015	Lightweight plastic carrier bags Directive – 94/62/EC	C – Product;
November	SET Plan Communication – C(2015) 6317	B - Process

2015		
December 2015	EC Proposal for a Directive on the landfilling of waste (COM(2015) 594)	D – EoL;
December 2015	Circular Economy Action Plan COM (2015) 614	E – Cross-cutting
February 2016	A global view of bio-based industries: benchmarking and monitoring their economic importance and future developments, JRC Technical Report	E – Cross-cutting
November 2016	UN/FCCC Paris Agreement	E – Cross-cutting
May 2017	JRC Science for Policy Report. Bioeconomy Report 2016.	E – Cross-cutting
March 2017	Amendment of the Proposal Directive on the landfilling of waste 2018/C263/31	D – EoL
June 2017	Study on Access-to-finance conditions for Investments in Bio-Based Industries and the Blue Economy – European Investment Bank	E – Cross-cutting
November 2017	EPR in the EU Plastics Strategy and the Circular Economy: A focus on plastic packaging (IEEP Report)	D – End of Life (EoL)
January 2018	A European Strategy for Plastics in a circular economy COM(2018) 28	B – Process; C – Product; D - EoL
January 2018	Communication on a monitoring framework for a circular economy COM(2018) 28	E – Cross-cutting
March 2018	Position of EUBP on the European Plastics Strategy	C - Product
March 2018	Emission Trading Scheme (ETS-) Directive - (EU) 2018/410	B – Process
March 2018	Commission action plan on financing sustainable growth COM(2018) 97 final	E – Cross-cutting
April 2018	OECD Meeting Policy Challenges for a Sustainable Bioeconomy	E – Cross-cutting
May 2018	Amendment of the Directive on landfill of waste Directive 2018/850	D - EoL
May 2018	Amendment of the Directive on Waste – Directive (EU) 2018/851	D - EoL
May 2018	Directive on packaging and packaging waste – Directive (EU) 2018/852	B – Process; C – Product; D - EoL
May 2018	Directive on organic production and labelling of organic products – (EC) 834/2007	A – Primary sourcing
May 2018	Guidance on Innovation Procurement – COM(2018) 3051	C – Product
May 2018	Proposal for a Single Use Plastics Directive – COM(2018) 340	C – Product, D – EoL
June 2018	Impact Assessment Accompanying the CAP Proposal – SWD (2018) 301	A – Primary sourcing
June 2018	Legislative Proposal on CAP beyond 2020 – COM(2018) 392	A – Primary sourcing
June 2018	EEA European Waters Report #7/2018	
June 2018	Revised Waste Legislative Framework	D – EoL
June 2018	A European Strategy for plastics in the circular economy. Local and regional dimension	D – End of Life (EoL)
October 2018	Regulation on (CLP) classification, labelling and packaging of substances and mixtures – (EU) 2018/1480	C – Product;
October 2018	A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment. Updated Bioeconomy Strategy – COM (2018) 673/2 & SWD (2018) 431	E – Cross-cutting
November 2018	Communication on A Clean Planet for all – COM(2018) 773	E – Cross-cutting;
November	OECD – Realising the circular Bioeconomy	E – Cross-cutting

2018		
December 2018	Legal Limits on Single-Use Plastics and Microplastics: A Global Review of National Laws and Regulations (UNEP)	E – Cross-cutting
December 2018	Directive on the promotion of the use of energy from renewable sources – 2018/2001/EU	A – Primary Sourcing, B – Process
December 2018	Directive amending 2012/27/EU on energy efficiency – Directive 2018/2002/EU	B – Process
December 2018	EMAS regulation – (EU) 2018/2026	B – Process
January 2019	EU Policy Coherence for Development (PCD) – SWD(2019) 20 final	E – Cross-cutting
January 2019	EC - Reflection Paper - Towards a Sustainable Europe by 2030	E – Cross-cutting
March 2019	Report on Implementation of Circular Economy Action Plan – COM(2019) 90 & SWD(2019) 91	E – Cross-cutting;
March 2019	Working Document on Sustainable Products in a Circular Economy – SWD(2019) 92	E – Cross-cutting;
June 2019	Regulation on EU fertilising products – (EU) 2019/1009	A – Primary Sourcing; D – EoL
June 2019	Single Use Plastics (SUP) Directive - (EU) 2019/904	C – Product; D – EoL
June 2019	New Plastics Economy Global Commitment Report (UNEP)	B – Process; C – Product; D – EoL; E – Cross-cutting
July 2019	OECD - Policy approaches to incentivise sustainable plastic design	B – Process; C – Product; D – EoL; E – Cross-cutting
July 2019	EU Action to Protect and Restore the World's Forests23,	A – Primary sourcing
November 2019	Directive on unfair commercial practices – (EU) 2019/2161	C - Product
December 2019	The European Green Deal – COM(2019) 640	A – Feedstock; B – Process; C – Product; D – EoL; E – Cross-cutting; no mentioning of the word "bio-based" or similar
February 2020	Sharing Europes Digital Future COM(2020) 67	Cross-cutting
March 2020	EU New Circular Economy Action Plan	B – Process; C – Product; D – EoL; E – Cross-cutting;
March 2020	A new industrial strategy for Europe - COM(2020) 102 final	B – Process; D - EoL
March 2020	Technical Expert Group (TEG) on Sustainable Finance Final Report on the EU Taxonomy	E – Cross-cutting

6.2 Upcoming and expected policy documents

Table 7: Expected official communications (as of March 2020) with potential impacts on the biobased materials sector. Source: own selection mainly based on the Annex of the Green Deal document and the EU New Circular Economy Action Plan.

Date	Communication	Stage(s) of the supply chain
Early 2020	EU Vision to the UNFCCC	E- Cross-cutting
~3rd quarter of 2020	European Climate Pact	E- Cross-cutting
~Spring 2020	Safeguarding nature – EU 2030 Biodiversity Strategy	A – Primary sourcing
May 2020	European climate law – achieving climate neutrality by 2050	E- Cross-cutting
Planned for First quarter 2020	Sustainable food – 'farm to fork' strategy	A – Primary sourcing
Summer 2020	Comprehensive plan to increase the EU 2030 climate target to at least 50% and towards 55% in a responsible way	E – Cross-cutting;

June 2020	Assessment of the final National Energy and Climate Plans	B - Process
2020	Renovation wave' initiative for the building sector	C - Product
2020	New EU Forest Strategy	A – Primary sourcing
From 2020	Measures to support deforestation-free value chains	A – Primary sourcing
January 2020???	Proposal for a Just Transition Mechanism, including a Just Transition Fund, and a Sustainable Europe Investment Plan	E – Cross-cutting
Autumn 2020	Renewed sustainable finance strategy	E – Cross-cutting
From 2020	Initiatives to screen and benchmark green budgeting practices of the Member States and of the EU	E – Cross-cutting
From 2020	Integration of the Sustainable Development Goals in the European Semester	E – Cross-cutting
2020	Proposal for an 8^{th} Environmental Action Programme	E – Cross-cutting
2020	Legislative proposal empowering consumers in the green transition	C - Product
2020	Legislative proposal on substantiating green claims	C - Product
as of 2020	Supporting the circular economy transition through the Skills Agenda, the forthcoming Action Plan for Social Economy, the Pact for Skills and the European Social Fund Plus	E – Cross-cutting
as of 2020	Supporting the circular economy transition through Cohesion policy funds, the Just Transition Mechanism and urban initiatives	E – Cross-cutting
as of 2020	Improving measurement, modelling and policy tools to capture synergies between the circular economy and climate change mitigation and adaptation at EU and national level	E – Cross-cutting
as of 2020	Leading efforts towards reaching a global agreement on plastics	C – Process, D - Product
as of 2020	Mainstreaming circular economy objectives in free trade agreements, in other bilateral, regional and multilateral processes and agreements, and in EU external policy funding instruments	E – Cross-cutting
2020/2021	Mainstreaming circular economy objectives in the context of the rules on non-financial reporting, and initiatives on sustainable corporate governance and on environmental accounting	E – Cross-cutting
~June 2021	Revision of all relevant climate-related policy following the review of Emissions Trading System Directive; Effort Sharing Regulation; Land use, land use change and forestry Regulation; Energy Efficiency Directive; Renewable Energy Directive;	B - Process
June 2021	Proposal for a revision of the Energy Taxation Directive	B - Process
2021	Proposal for a carbon border adjustment mechanism for selected sectors	A – Primary sourcing, C - Product
2021	Zero pollution action plan for water, air and soil	B - Process
2021	Revision of measures to address pollution from large industrial installations	B - Process
2021	Legislative proposal for a sustainable product policy initiative	C - Product
2021	Legislative and non-legislative measures establishing a new "right to repair"	D – End of Life
as of 2021	Mandatory Green Public Procurement (GPP) criteria and targets in sectoral legislation and phasing-in mandatory reporting on GPP	C - Product
as of 2021	Review of the Industrial Emissions Directive, including the integration of circular economy practices in upcoming Best Available Techniques reference documents	B - Process

2021	Review to reinforce the essential requirements for packaging and reduce (over)packaging and packaging waste	D – End of Life
2021	Restriction of intentionally added microplastics and measures on unintentional release of microplastics	C - Product
2021	**Policy framework for bio-based plastics and biodegradable or compostable plastics**	**C - Product**
2021	EU Strategy for Textiles	C -Product
2021	Strategy for a Sustainable Built Environment	C - Product
2021	Initiative to substitute single-use packaging, tableware and cutlery by reusable products in food services	D – End of Life
2021	Methodologies to track and minimise the presence of substances of concern in recycled materials and articles made thereof	D – End of Life
2021	Harmonised information systems for the presence of substances of concern	C - Product
2021	Scoping the development of further EU-wide end-of-waste and by-product criteria	D – End of Life
2021	Revision of the rules on waste shipments	D – End of Life
2021	Reflecting circular economy objectives in the revision of the guidelines on state aid in the field of environment and energy	B – Process, D – End of Life
2021	Updating the Circular Economy Monitoring Framework to reflect new policy priorities and develop further indicators on resource use, including consumption and material footprints	E – Cross cutting, D – End of Life
as of 2021	Proposing a Global Circular Economy Alliance and initiating discussions on an international agreement on the management of natural resources	E – Cross cutting, D – End of Life
2021/2022	Mandatory requirements on recycled plastic content and plastic waste reduction measures for key products such as packaging, construction materials and vehicles	D – End of Life
~2022	Revised common agricultural policy (CAP)	A – Primary sourcing
2022	Launch of an industry-led industrial symbiosis reporting and certification system	B - Process
2022	Review of the rules on proper treatment of waste oils	D – End of Life
2022	Waste reduction targets for specific streams and other measures on waste prevention	D – End of Life
2022	EU-wide harmonised model for separate collection of waste and labelling to facilitate separate collection	D – End of Life
2023	Regulatory framework for the certification of carbon removals	A – Primary sourcing

6.3 Workshop Agendas and Main Outcomes

The stakeholder participatory group modelling workshop agendas, as well as some of the main outcomes captured from these workshops have been presented below:

WP9: SyD-ProBio Workshop

Wednesday, November 14th, 2018

VENUE: BiT -Unitelma Sapienza, Viale Regina Elena 291, Rome, Italy

TIME: 09.00 a.m. - 15.30 pm

AGENDA

09.00 - 09.30 Welcome and objectives. Task 9.5 at a glance

- *Problem structuring and model's boundaries*
- *Choice of the bio-based sector/products to be included in the analysis as case study*

09.30 - 10.30 Understanding the transition to a bio-based economy through the lens of system dynamics methodology

- *Introduction to key concepts of systems thinking and systems dynamics*

10.30 - 10.45 Coffee break

10.45 - 12.45 Setting the model's boundary - brainstorming session

12.45 - 13.30 Lunch break

13.30 - 15.15 Which bio-based sector/ products should we include in the model?

15.15 - 15.30 Wrap-up & next steps

WP9: SyD-ProBio Workshop

Thursday, November 30th, 2018

VENUE: Swedish Environmental Protection Agency (Naturvårdsverket)

Valhallavägen 195, Stockholm, Sweden

ROOM: Kosterhavet K0 123

TIME: 11.00 am - 17.30 pm.

AGENDA

11:00 – 11.30 Welcome and objectives of today's workshop

- *Sustainability criteria for bio-based products*
- *Mapping policy instruments*
- *What does an "optimal" instrument mix for European bio-based products policy look like? Which new instruments do we need?*

11.30 - 12.00 Main outcomes of the 1st workshop - brief overview

12.00 – 13.30 Working session 1

13.30 – 14.00 Lunch break

14.00 – 15.20 Working session 2

15.20 – 15.30 Coffee Break

15.30 – 16.30 Working session 3

16.30 – 17.15 Brainstorming session on work alignment between Task 9.3, Task 9.4, Task 9.5 and SAT-ProBio document (WP8)

17.15 – 17.30 Wrap-up & next steps

WP9: SyD-ProBio Workshop

Friday, January 11, 2019

VENUE: Conference room- Chair of Innovation Economics, TUB
Room 2007, Marchstrasse 23
10587 Berlin
TIME: 09.00 am - 15.30 pm.

AGENDA

09:00 – 09:30 Welcome and objectives of today's workshop

- *Confirmation of systems boundaries*
- *Bio-based plastics in Europe - identify key components to be included in the model*
- *Elaborate on the relevant policy instruments mapped in Stockholm's Workshop*
- *Identify other policy instruments & mixes*

09.30 – 11.00 Working session 1 (based on the main outcomes of the first two workshops held in Rome and Stockholm)

11.00 – 11.15 Coffee break

11.15 – 13.30 Working session 2 - Policy instruments

13.30 – 14.30 Lunch break

14.30 – 15.30 Wrap-up & next steps

WP9: SyD-ProBio Workshop

March 6-8, 2019

VENUE: Lund University, Centre for Environmental and Climate Research (CEC)
Sölvegatan 37, SE-223 62, Lund-SWEDEN
TIME: March 6 - 14.30 - 17.30 p.m., March 7 - 09.00 a.m. - 17.00 pm,
March 8 - 09.00 a.m. - 14.00 pm

AGENDA

March 6
14:30 – 17.30 ***Session Objectives***

- *Analysis of outcomes of group modelling workshops held in Rome, Stockholm and Berlin*

March 7
09.00 - 17.00 Hands-on Session

- *Validation of causal loop diagrams from previous workshops*
- *SyD-ProBio sub-models formulation*

March 8
09.00 – 14.00 ***Session Objectives***

- *What does an "optimal" instrument mix for European bio-based products policy look like?*
- *Criteria for defining the policy mixes*
- *Design the next workshop in Santiago de Compostela*

WP9: SyD-ProBio Workshop

Wednesday, April 3rd , 2019

VENUE: Escola Técnica Superior de Enxeñaría (ETSE), Rúa Lope Gómez de Marzoa, Campus Vida (Campus Sur), Santiago de Compostela
TIME: 14.00 - 16.45 pm

AGENDA

14.00 - 14.15 Welcome and objectives

- *Selection of key policy instruments and measures to be tested in SyD-ProBio model*
- *Joint decision on the level of detail of the policy mix (e.g. supply side, demand side, cross-cutting policies, scales of action)*

14.15 - 15.45 Hands-on session 1 - Policy instruments & mix

- *Working group 1: Phasing out fossil based polymers*
- *Working group 2: Making bio-based polymers more compatible (functionally replacing the oil- based)*
- *Working group 3: Promoting market uptake of bio-based polymers*
- *Working group 4: Making sure that bio-based polymers are sustainable*

15.45 - 16.00 Coffee break

16.00- 16.45 Wrap-up and next steps

WP9: SyD-ProBio Workshop

Thursday, June 13th, 2019

VENUE: LUISS Guido Carli University of Rome, Department of Law, Via Parenzo 11, 00198, Rome
TIME: 16.00 -18.30 p.m.

AGENDA

16.00 - 16.05 Welcome

16.05 - 17.10 Synergies between various tasks and SyD-ProBio model

- *How can the results of the tasks be integrated into the SyD-ProBio model?*
- *What elements of SAT-ProBio scheme could be included and tested in the SyD-ProBio model?*
- *What are the best ways of capturing the co-regulation framework[1] (developed in Task 9.3) into the SyD-ProBio? Is it feasible to develop a policy scenario for each type of co-regulation identified in Task 9.3?*
- *Data availability shortcomings, how to address them?*

17.10 - 17.20 Coffee break

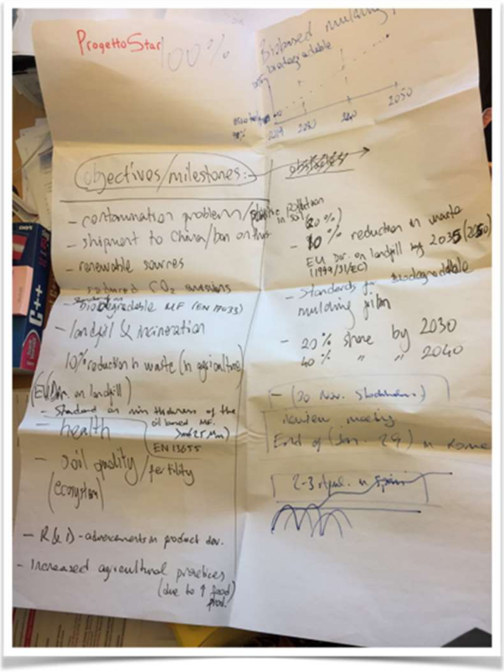
17.20 - 18.25 Policy mixes and policy scenarios to be tested

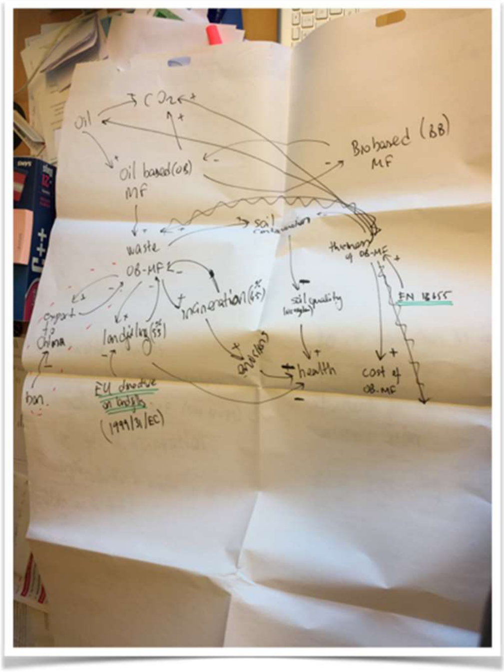
- *Set up a coherent approach regarding the policy mixes to be tested in the model, and the policy recommendations*
- *Agree on a set of criteria for defining the policy mixes*
- *Agree on a set of criteria for defining and assesing policy scenarios*

18.25 – 18.30 Closing remarks

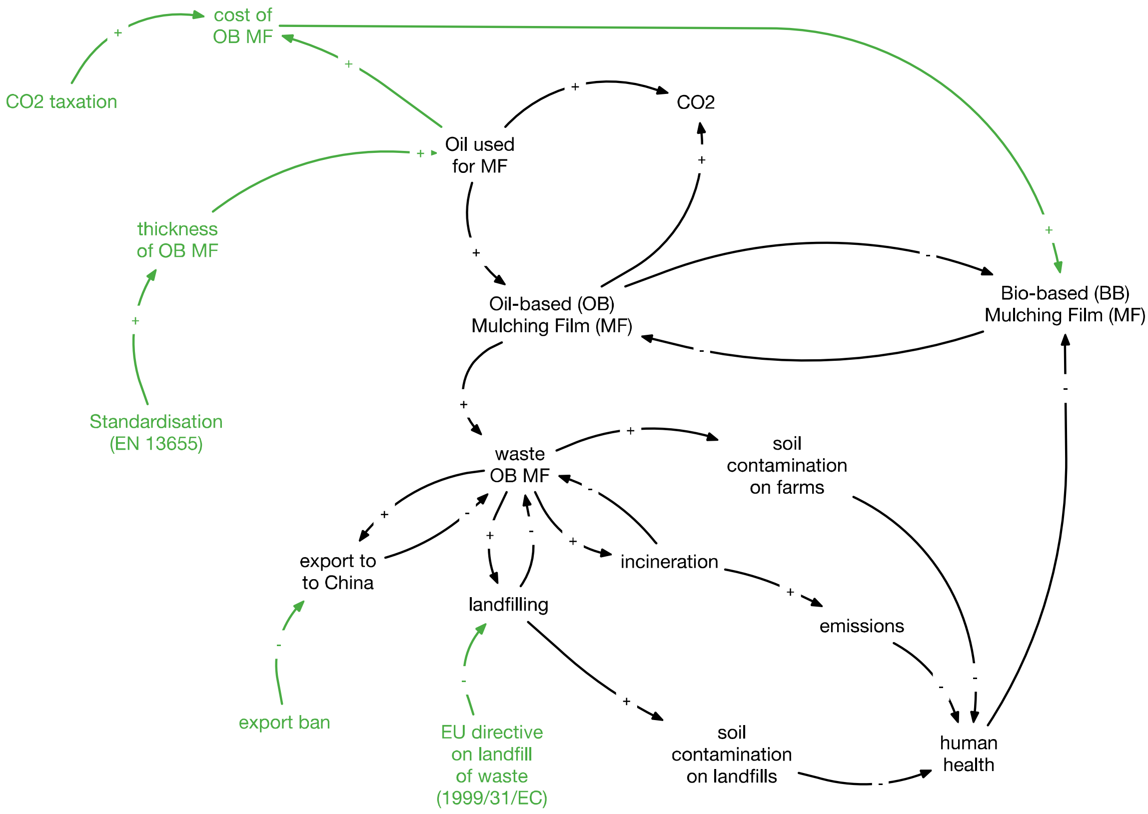
Rome workshop (2018-11-13/14):

The aim was to define system boundaries, what sector product group we will include in our analsyis and modelling work



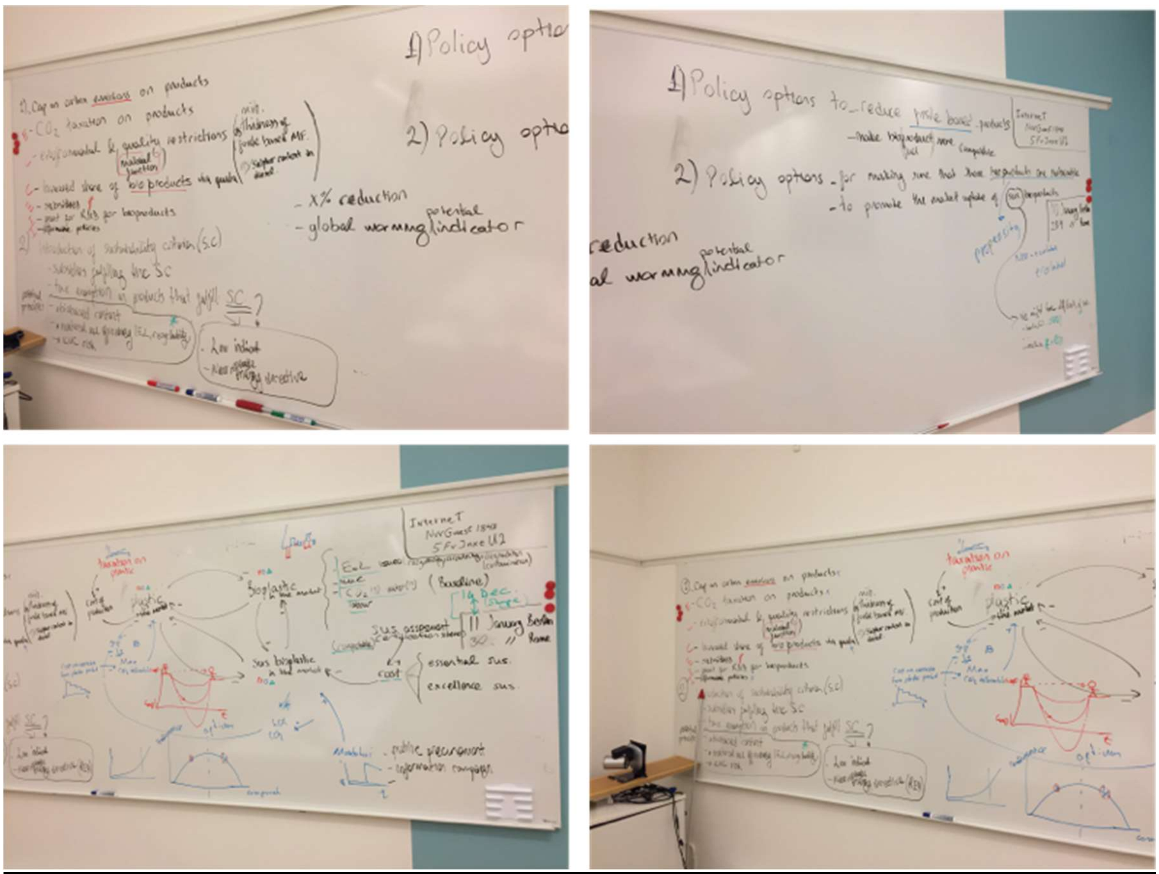


- contamination / plastic pollution
- ban on export of waste mulching film to China
- increased demand in renewable resource use
- reduced CO2 emissions with biobased material use
- standard on biodegrade mulching film (EN 17033)
- landfill and incineration of oil based mulching film waste
- EU directive on landfill of waste
- standard on minimum thickness of the oil based mulching film (EN 13655)
- health issues
- soil (ecosystem) quality, soil fertility
- R&D, advancement in product development
- increased agricultural production due to increased food demand



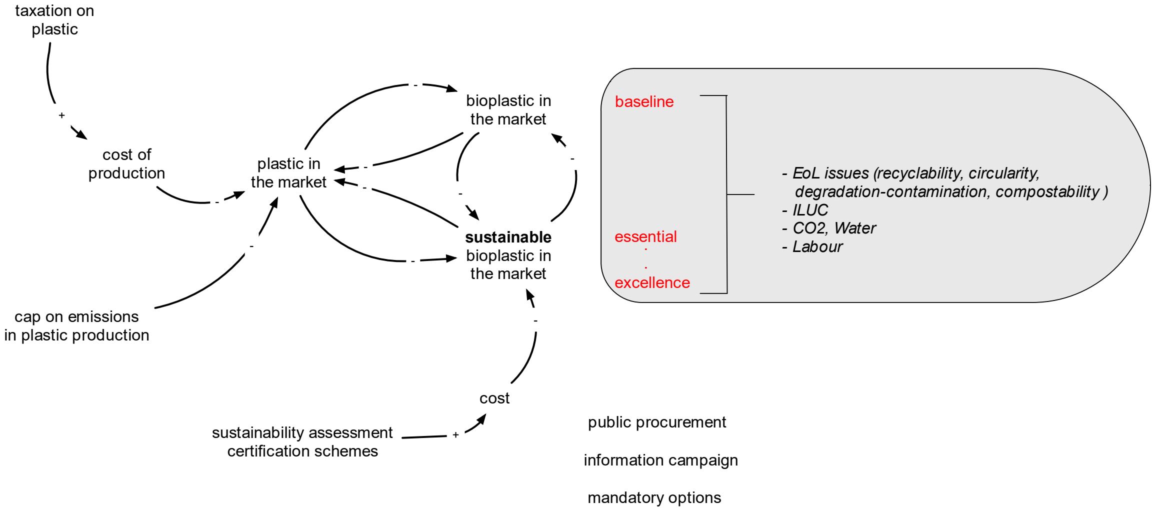
Stockholm workshop (2018-11-30):

The aim was to identify potential relevant policy mixes to be tested in the model



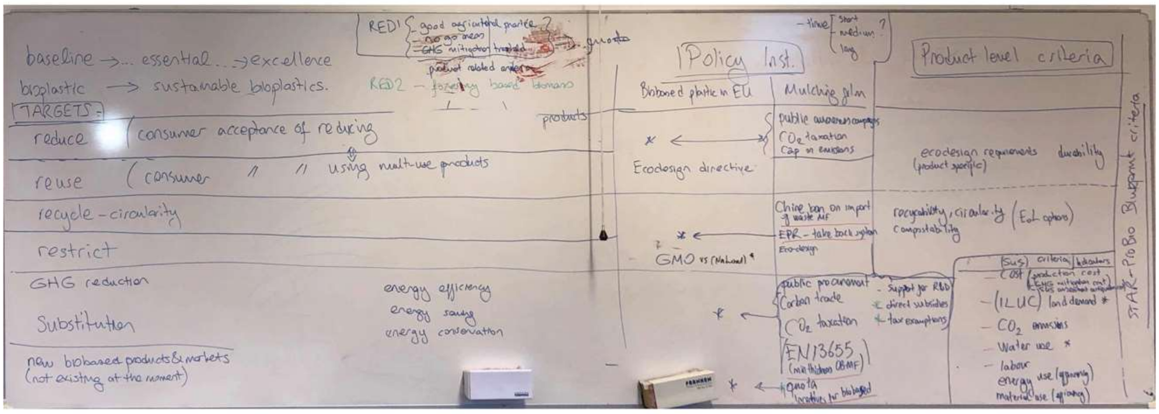
Aim	1. Policy options • To reduce fossile based products • To make bioproducts (biofuel) more compatible	2. Policy options • For making sure that these bioproducts are sustainable • To promote the market uptake of **sustainable** bioproducts
Policy type	Cap on carbon emission on products • CO2 taxation on products (E) • Environmental & quality (material function) restrictions (e.g. min thinkness of fossile based mulching film, sulphur content in diesel) (C) • Increased share of bioproducts via quata (C) • Subsidies (E) • Grant for R&D for bioproducts (E) • Informative policies (I)	Introduction of sustainability criteria • Subsidies fulfilling the sustainability criteria • Tax exemption on products that fulfill sustainability criteria
Notes	X% reduction in emissions Global warming potential indicator	Potential principles are: • Biobased content • Material use efficiency (EoL, recyclability, circularity) • ILUC risk New renewable energy directive sets principles for biofuel

different type of policies: informative, economic, voluntary, collaborative
Include minutes from the meeting



Berlin workshop (2019-01-11):

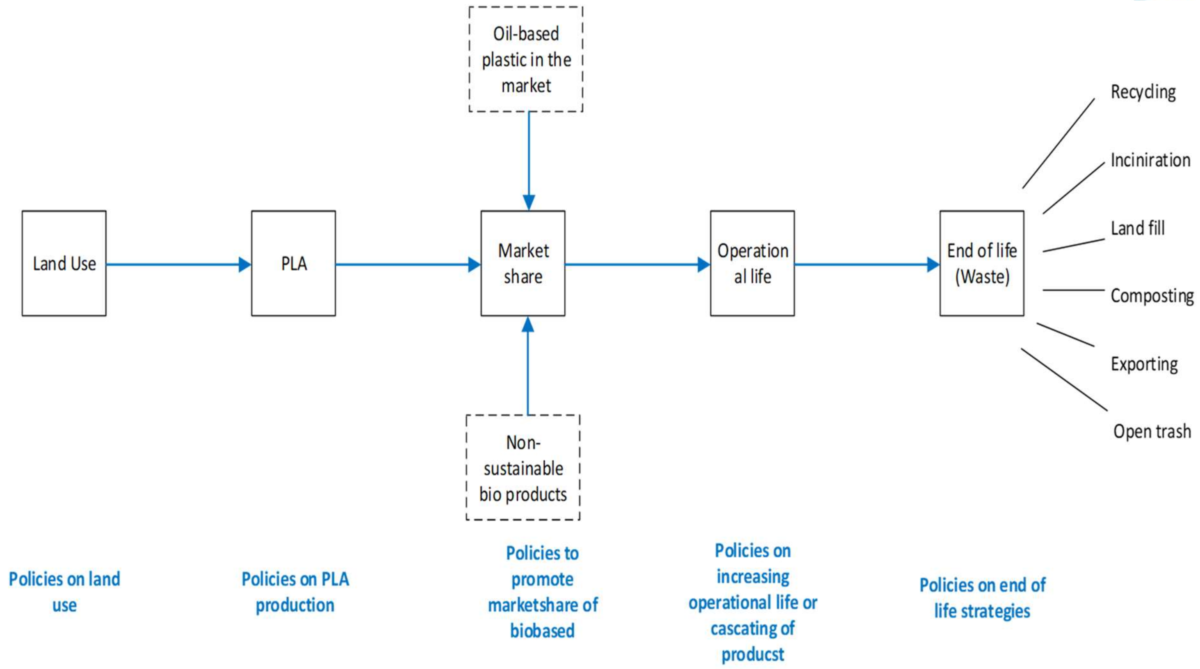
The aim was to have consensus on the policy options to be tested on the model (i.e. elaborate on the relevant policy mixes already identified in the previous workshop and to identify other important policy mixes)

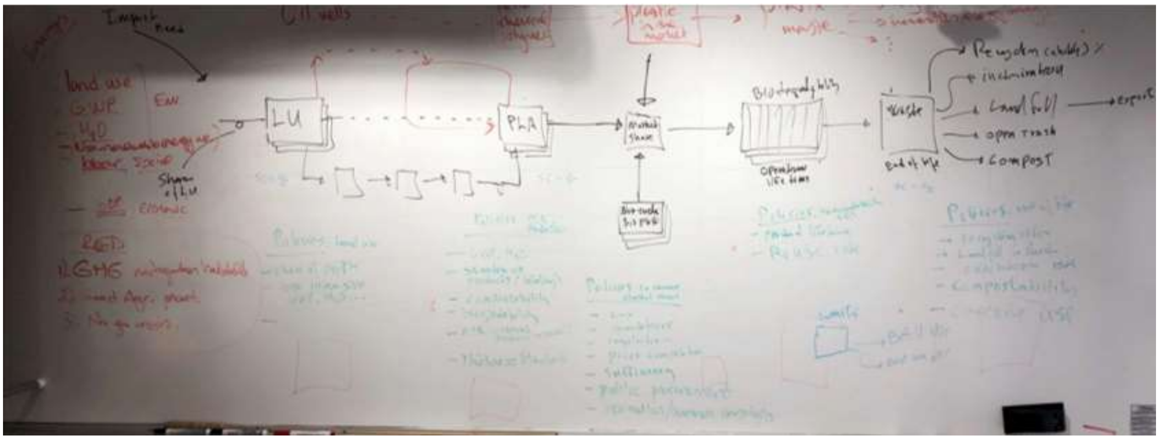

baseline → ... essential ... → excellence
bioplastic → sustainable bioplastics
TARGETS
reduce
consumer acceptance of reducing
reuse
recycle - circularity
restrict
GHG reduction
Substitution
new biobased products & markets
(not existing at the moment)
energy efficiency
energy saving
energy conservation
Policy Inst.
Product level criteria
Mulching film
Ecodesign directive
GMO
Carbon trade
CO2 taxation
EN13655
ecodesign requirements
durability
compostability
Cost
(ILUC) land demand
CO2 emissions
Water use
labour
STAR-ProBio Blueprint criteria

<table>
<tr><th rowspan="2">Targets</th><th colspan="2">Policy instruments</th><th rowspan="2">Product level criteria</th><th rowspan="2">Sustainability criteria / indicators</th></tr>
<tr><th>Biobased plastic in EU</th><th>Mulching film</th></tr>
<tr><td>Reduce (consumer acceptance of reducing products)</td><td rowspan="2">• Public awareness campaigns
• CO2 taxation
• Cap on emissions
• Ecodesign directive
•</td><td rowspan="2">• Public awareness campaigns
• CO2 taxation
• Cap on emissions</td><td rowspan="2">• Ecodesign requirements durability</td><td rowspan="7">• Cost (production cost, GHG mitigation cost, sustainability assessment certification cost)
• Land demand (ILUC)
• CO2 emissions (GWP)
• Water use
• Labour
• Energy use (efficiency)
• Material use (efficiency)</td></tr>
<tr><td>Reuse (consumer acceptance of using multi-use products)</td></tr>
<tr><td>Recycle-circularity</td><td>• EPR – take back system</td><td>• EPR – take back system
• Chinese ban on import of waste mulching film
• Eco design
•</td><td>• Recyclability
• Circularity
• Compostability
• Other EoL options</td></tr>
<tr><td>restrict</td><td>• GMO vs natural
•</td><td></td><td></td></tr>
<tr><td>GHG reduction</td><td rowspan="3">• Public procurement
• Carbon trade
• CO2 taxation
• Support for R&D
• Direct subsidies
• Tax exemptions</td><td rowspan="3">• EN 13655 (min. thickness for oil based mulching film)
• Public procurement
• Carbon trade
• CO2 taxation
• Support for R&D
• Direct subsidies
• Tax exemptions
• Quota and incentives for biobased
•</td><td rowspan="3"></td></tr>
<tr><td>Substitution</td></tr>
<tr><td>New biobased products & markets (not existing today)</td></tr>
</table>

Lund workshop (2019-03-06/08):

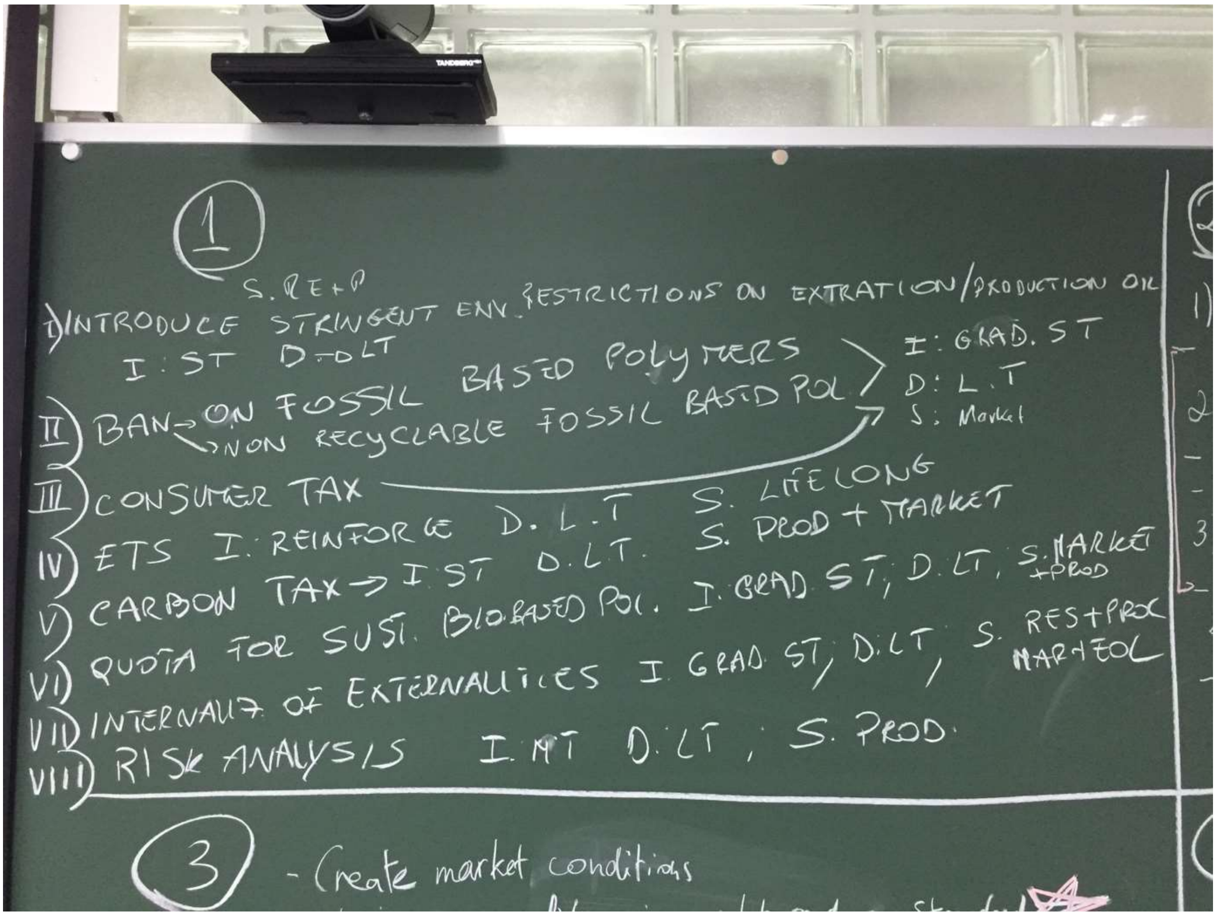
The aim was to agree upon an approach to identify policy fields, instruments and measures, which will be tested in SyD-ProBio model.

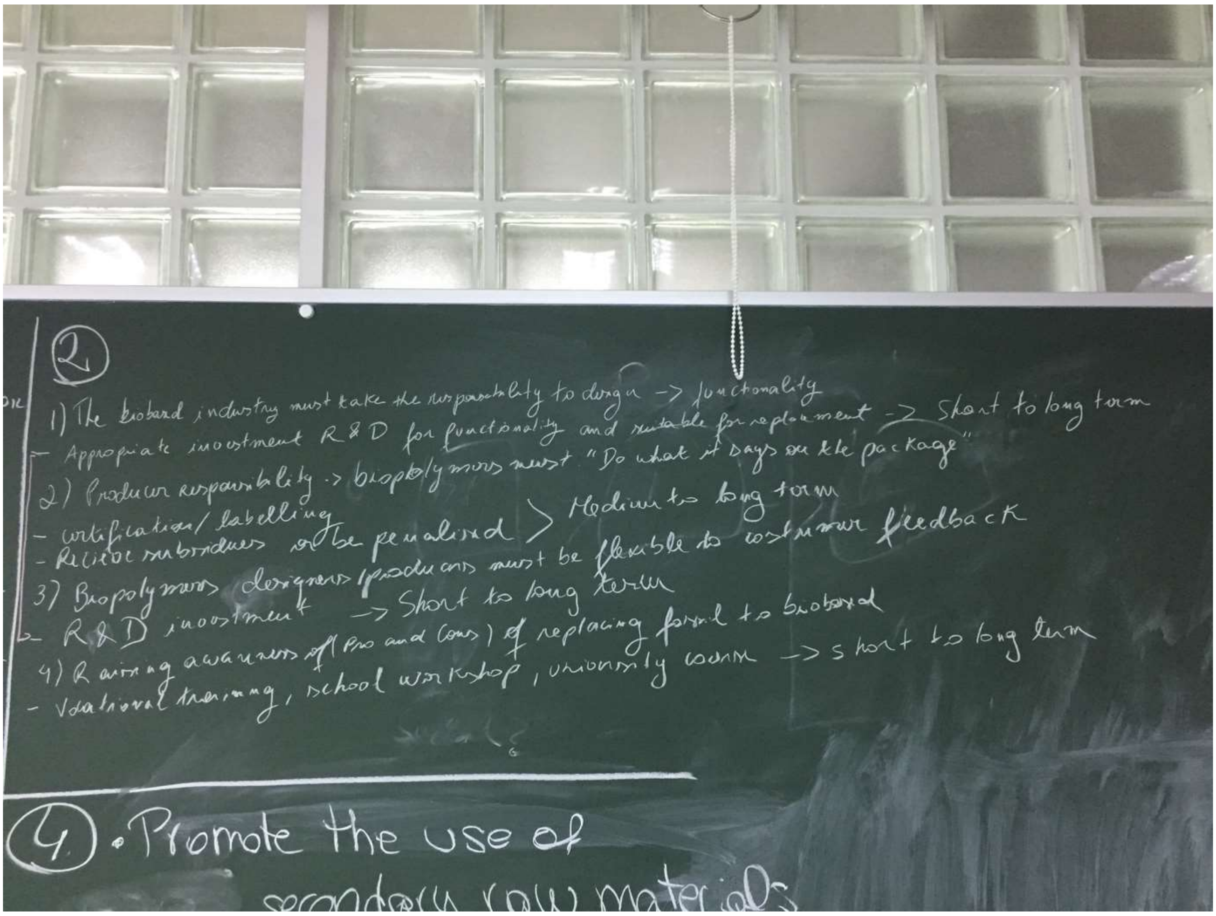


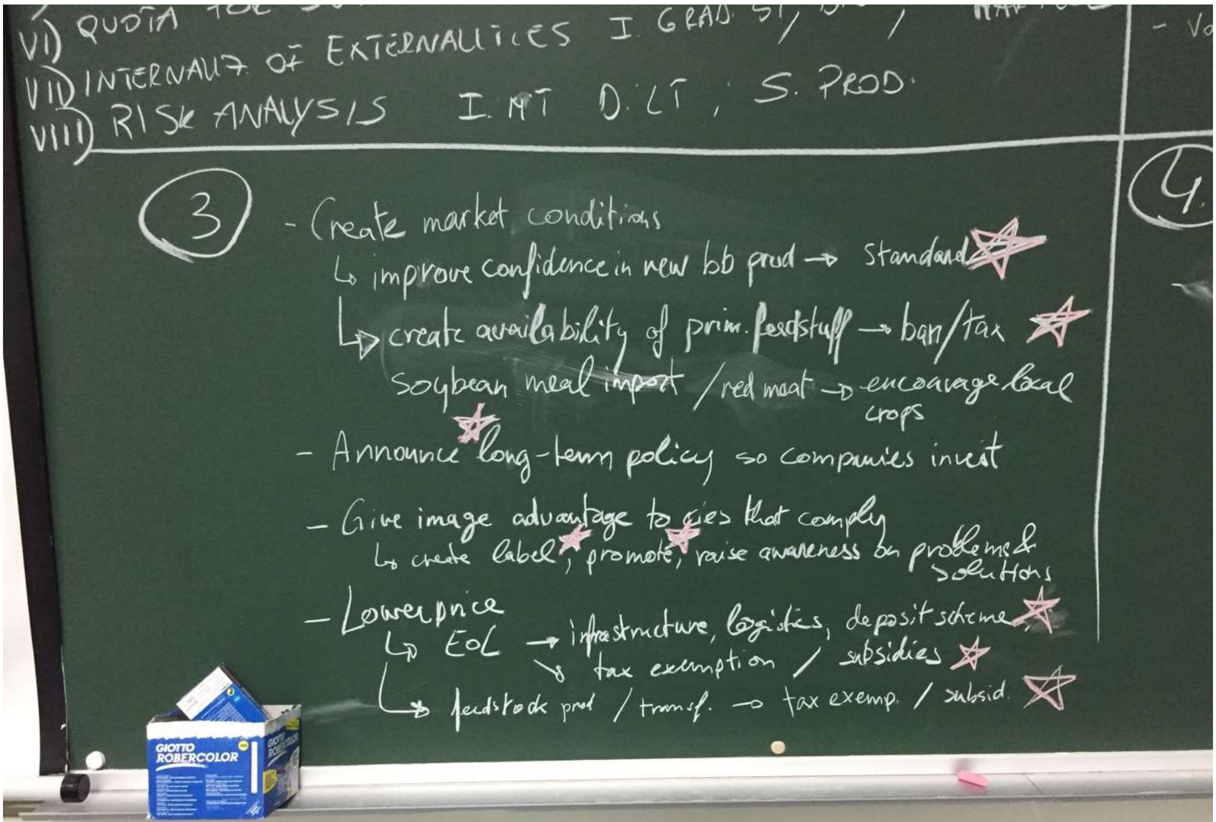


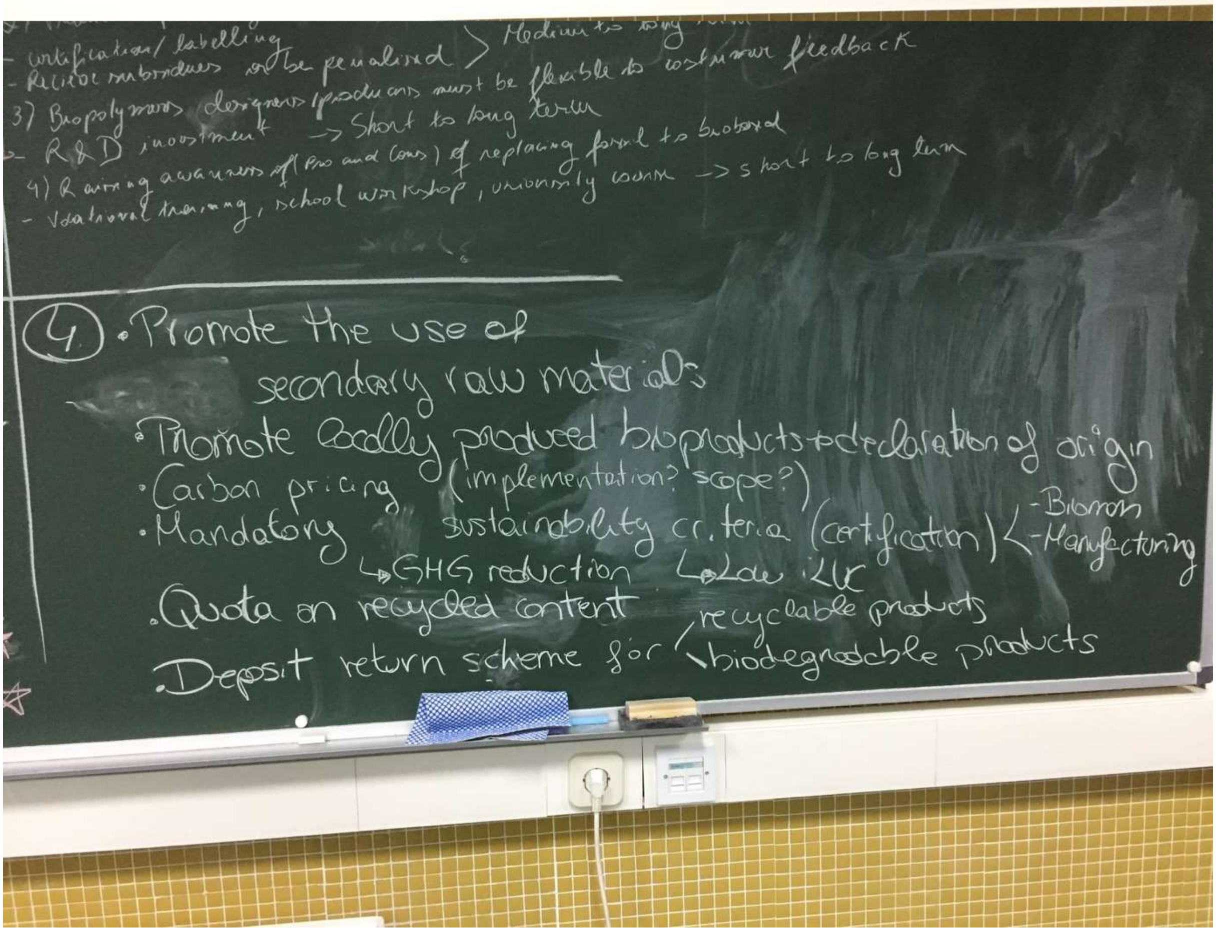
Santiago del Compostello workshop (2019-04-03):

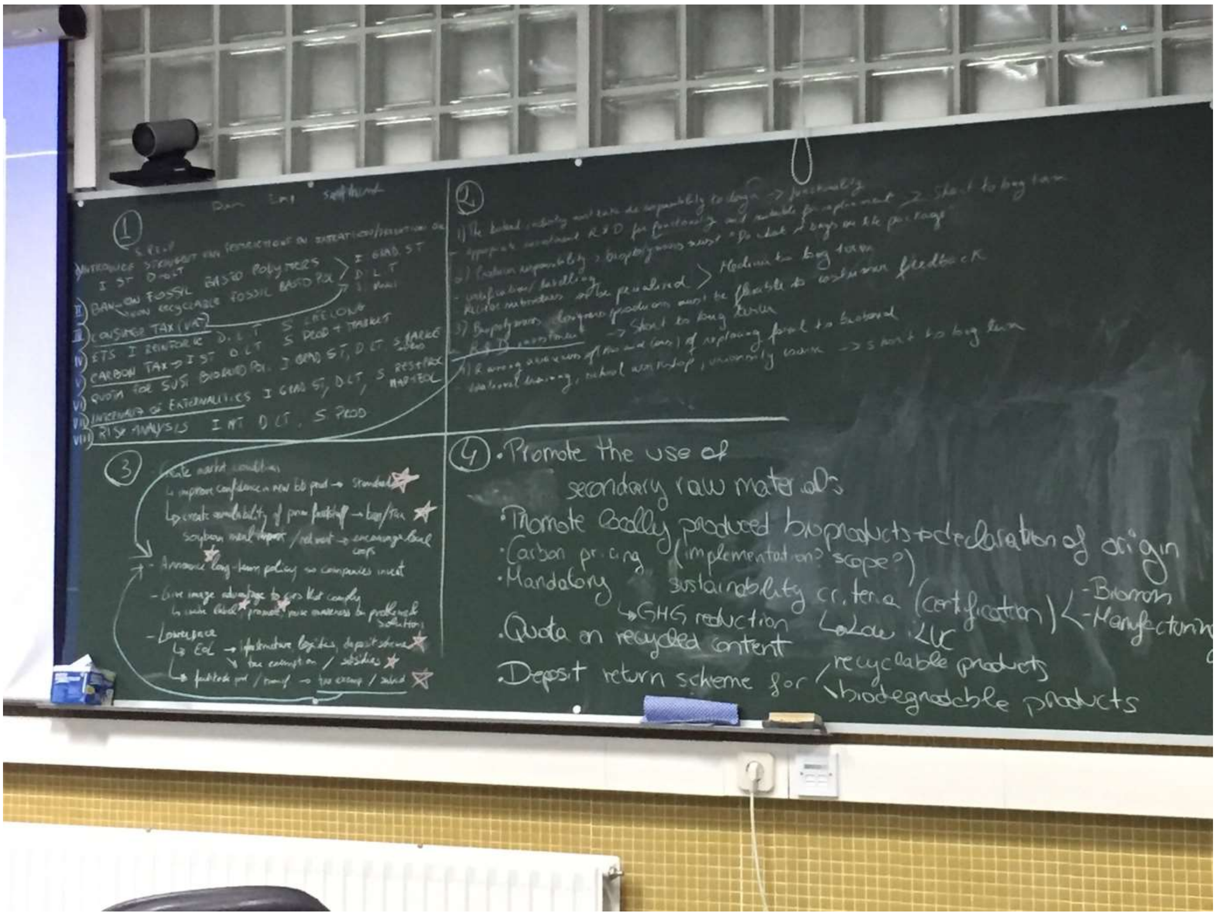
The aim was to identify a set of policy fields, instruments and measures, and select key mixes which will be tested in SyD-ProBio model.


1
S. RE+P
I) INTRODUCE STRINGENT ENV. RESTRICTIONS ON EXTRATION/PRODUCTION OIL
I: ST D: LT
II) BAN ON FOSSIL BASED POLYMERS
NON RECYCLABLE FOSSIL BASED POL
I: GRAD. ST
D: L.T
S: Market
III) CONSUMER TAX
S. LIFELONG
IV) ETS I. REINFORCE D. L.T S. PROD + MARKET
V) CARBON TAX → I ST D. LT.
I. GRAD ST, D. LT, S. MARKET +PROD
VI) QUOTA FOR SUST. BIOBASED POL.
S. REST+PROD MARKET EOL
VII) INTERNALIZ. OF EXTERNALITIES I. GRAD ST, D. LT,
VIII) RISK ANALYSIS I. MT D. LT, S. PROD.
3 - Create market conditions


2
1) The biobased industry must take the responsability to design -> functionality
- Appropriate investment R&D for functionality and suitable for replacement -> Short to long term
"Do what it says on the package"
2) Producer responsability -> biopolymers must
- certification/labelling
Medium to long term
- be penalized
must be flexible to costumer feedback
3) Biopolymers designers/producers
-> Short to long term
- R&D investment
of replacing fossil to biobased
4) Raising awareness
-> short to long term
- Vocational training, school workshop,
4. Promote the use of
secondary raw materials


VII) INTERNALIZ. OF EXTERNALITIES I. GRAD. ST
VIII) RISK ANALYSIS I. MT D. LT ; S. PROD.
3
- Create market conditions
↳ improve confidence in new bb prod → Standard
↳ create availability of prim. feedstuff → ban/tax
soybean meal import / red meat → encourage local crops
- Announce long-term policy so companies invest
- Give image advantage to cies that comply
↳ create label, promote, raise awareness on problems & solutions
- Lower price
↳ EoL → infrastructure, logistics, deposit scheme
↘ tax exemption / subsidies
↳ feedstock prod / transf. → tax exemp. / subsid.
4


4 · Promote the use of secondary raw materials
· Promote locally produced bioproducts → declaration of origin
· Carbon pricing (implementation? scope?)
· Mandatory sustainability criteria (certification) - Biomass - Manufacturing
↳ GHG reduction ↳ Low ILUC
· Quota on recycled content
· Deposit return scheme for recyclable products / biodegradable products


4
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Carbon pricing (implementation? scope?)
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GHG reduction
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