Work Package 1 – Shared modelling framework and learnings

D1.2 – Description of scientific methods

Task 1.2 – Framework for foreground life cycle inventory of bio-based sectors

Method for modelling constraints to biomass availability

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This document is a part of the ALIGNED project (grant no. 101059430) deliverable D1.2. The document presents a method to model constraints to biomass availability under different situations. First it provides a theoretical introduction to how the problem is approached from a consequential perspective. Furthermore, specific recommendations are provided for modelling supply of biomass in line with this theory and indications for which types of data to use with respect to the methodological choices are provided.

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Acronyms and abbreviations

ABBREVIATIONS	Description
WP	Work Package
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life Cycle Impact Assessment
FAOSTAT	Food and agriculture statistics of the United Nations
JRC	Joint Research Centre – European Commission

Executive summary

This document addresses the challenges related to increase in demand for bio-based products that will lead to a competition for biomass supply. The issue of supply constraints is considered in consequential LCA modelling. Market constraints could be due to multiple issues: geographical, production capacity, co-production, and policy. This document elaborates on how supply constraints are identified using decision trees based on the consequential modelling approach. Besides constraints, this document also provides recommendations to identify marginal suppliers of resources using production projections or historical trends. The method to identify constraints and marginal supply has been elaborated with specific examples related to bio-based materials and products. This document also explains why the retrospective (i.e., attributional) modelling cannot be used to address the issues related to competition of biomass supply. This is primarily because attributional modelling does consider the cascading effects due to increase in demand of a resource and hence disregards potential constraints. Finally, this document recommends modelling choices in the order of complexity and validity to support studies using biomass resources regarding competition and constraints of biomass supply.

1. Consequential modelling approaches to consider constraints in biomass within the context of life cycle assessment.

The transition to - a non-fossil bioeconomy will translate in a substantial increase in the need for biomass, that will be required in several sectors and industries, putting additional pressure to the producers of bio-based feedstock materials. The availability of specific feedstocks and biomass types might be “constrained” (i.e., limited) and this has consequences on what the impact induced by producing more bio-based **products** will be. This is one of the aspects addressed in WP1 of the ALIGNED project.

LCA methodological aspect (and related ISO phase)	Modelling challenge in bio-based products	State of the Art	Research needs	Contribution of ALIGNED
Model competition for biomass (Life cycle Inventory)	Determining the effects of increasing demand for bio-based materials given that biomass supply can’t increase indefinitely, and multiple sectors target the same biomass.	A sound consequential framework exists but not yet operational, each study uses different models and assumptions.	Identification of sustainability constraints and caps to biomass use or products	Develop models that can simulate competition between uses as well as estimate expected trends in supply for different biomaterials, considering existing constraints.

Table 1. Addressing the challenge of modelling competition for biomass in ALIGNED

Solving this problem resolves to start asking different questions when doing the Life Cycle Assessment (LCA). Currently, the common and widely dominant approach is to retrospectively ask questions like *“What is inside this product?”* and *“How can I trace back the impact that occurred in producing this product”*? These questions, although valuable for many, do not help us understand what the effects will be, the consequences, and the impacts of producing more of these products tomorrow. To understand this, there is the need to prospectively start asking questions such as *“What happens when more of this feedstock is needed?” “What happens if we start producing this bio-based product?” “What is currently happening to this residual material and what will be the effect of my decision of using it?” “What is the impact related to all these cascading effects?”.*

Below follows a series of decision trees to illustrate how the modelling of the problem of including constrained biomass in LCA can be approached using a consequential approach (Weidema et al., 2018). This is based on existing consequential LCA theory[1], a *“System modelling approach in which activities in a product system are linked so that activities are*

[1] An organized collection of the main elements of consequential theory is publicly available at https://consequential-lca.org/

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included in the product system to the extent that they are expected to change as a consequence of a change in demand for the functional unit" (UNEP, 2011).

While the underlying theories have been already documented in literature, the contribution of the ALIGNED project is on recommending which data and tools to use to apply these models and theories and to increase the robustness of their results. The reason why decision trees are here used rather than a system model or product system flow model is that this document takes the perspective of a LCA practitioner, which is the target audience of the ALIGNED project, who is doing the LCA of the bio-based product and that is therefore prompted to ask specific questions and to back up the modelling choices with evidence.

A possible representation of the problem is illustrated in Figure 1.

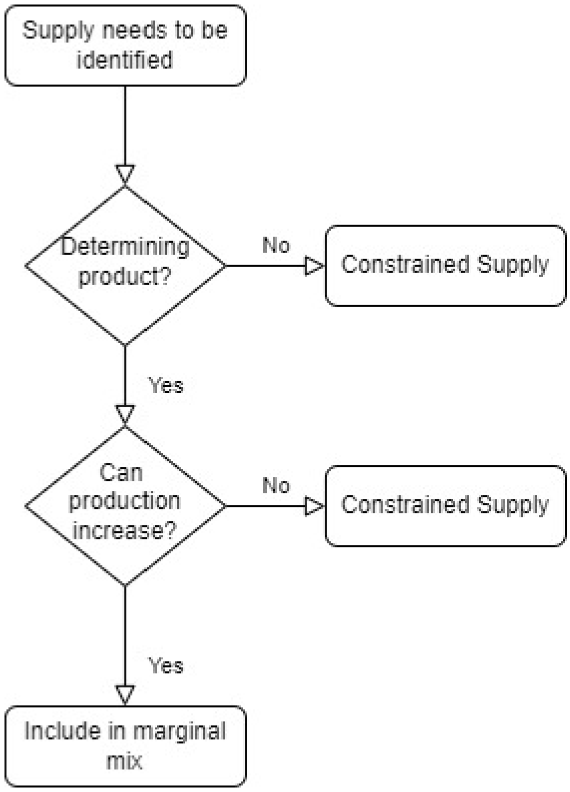

Figure 1 Decision tree to identify constrained supply

A certain producer needs an input of bio-based material for producing a specific product, and the producer needs to understand the impact associated with the supply of such material. The first task is to understand whether the product is a main (determining) product of a specific activity, or if it is a (dependent) by-product – as this will tell whether there is a constrain or not. This is a basic example of consequential modelling.

A determining product is such that an increase in the demand of this product increases the production volume of the activity. Such a product is usually the main source of revenue for the producing activity, therefore has high market demand. Conversely, increase in demand of (dependent) by-products does not influence the production volume of the activity. Hence, dependent products are always constrained. Increase in demand of constrained products can influence the supply chain depending on the market and the timeline. The increase in demand of constrained products with no market in the short term will avoid current treatment activities (e.g. waste treatment). The increase in demand of constrained products

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for which there is an already established market (and there will be in the long term) lead to divergence of use and hence induce production from marginal suppliers.

A more detailed flow chart (Figure 2) shows all the range of possibilities. The grey boxes indicate the type of data that need to be used to increase the robustness of the results of the model, that is also where the contribution of the ALIGNED project lies. **The ALIGNED project intends to provide data, tools, and scientific evidence to help moving across this decision tree and to back-up the modelling choices.**

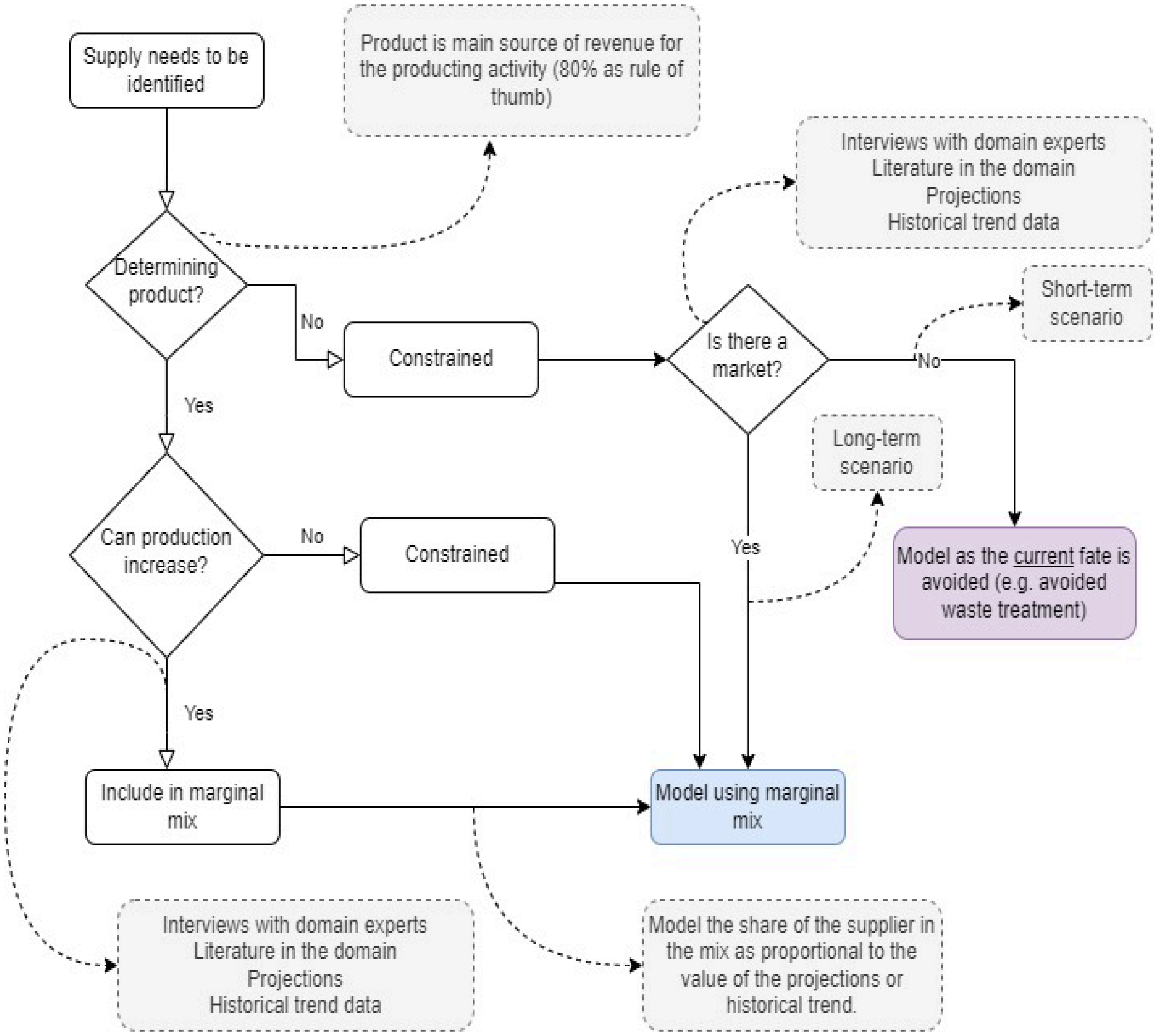

Figure 2 Expanded decision tree to identify constraints and marginal suppliers and how they are modelled.

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2.Examples of how the method can be applied to different cases

In the following we include some examples for applying this modelling framework to specific cases related to bio-based materials and products.

Example 1: Timber for construction. This is a straightforward example as timber is the main and determining product of most forest plantations in Europe. Therefore, the increased demand for this product will very likely trigger additional plantation, i.e. an expansion of current production. The main problem is understanding which supplier is to be included in a potential "timber market" and how to identify such unconstrained suppliers. Will they all be in EU? How much will each supplier contribute to the increase in demand? Etc.

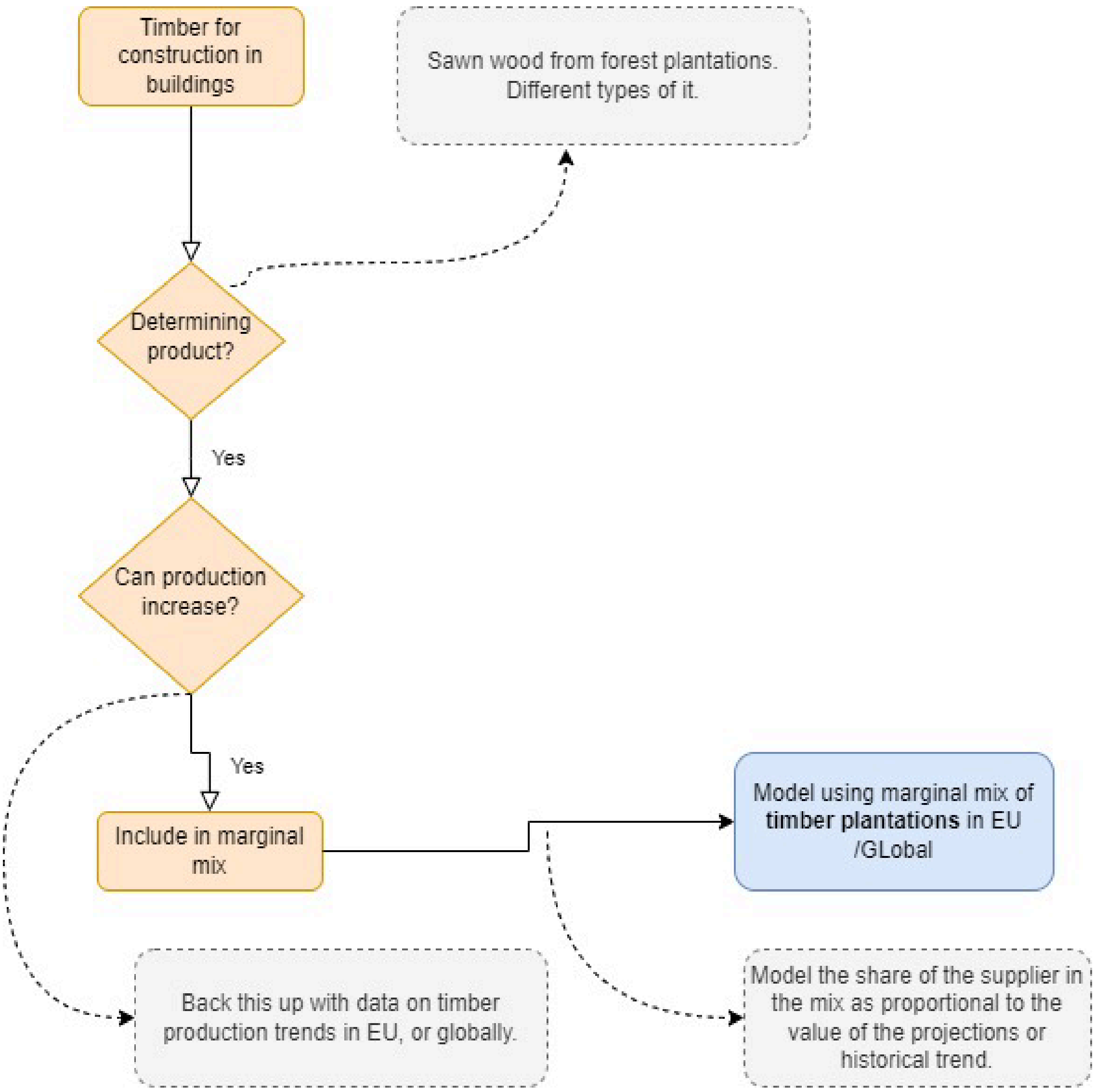

Figure 3 The decision tree applied to understand the feedstock supply for the use of sawn timber in construction. In this case the feedstock is non-constrained, hence the model needs to identify marginal sources of timber.

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Example 2: Primary wood chips for production of a wood panel. Wood chips can be obtained both from dedicated short-rotation plantations[2] (Rödl, 2017) and or as a residue from the timber industry (see previous example and next). In this example, we consider primary wood chips i.e., supplied directly from short rotation plantations of trees produced for chipping.

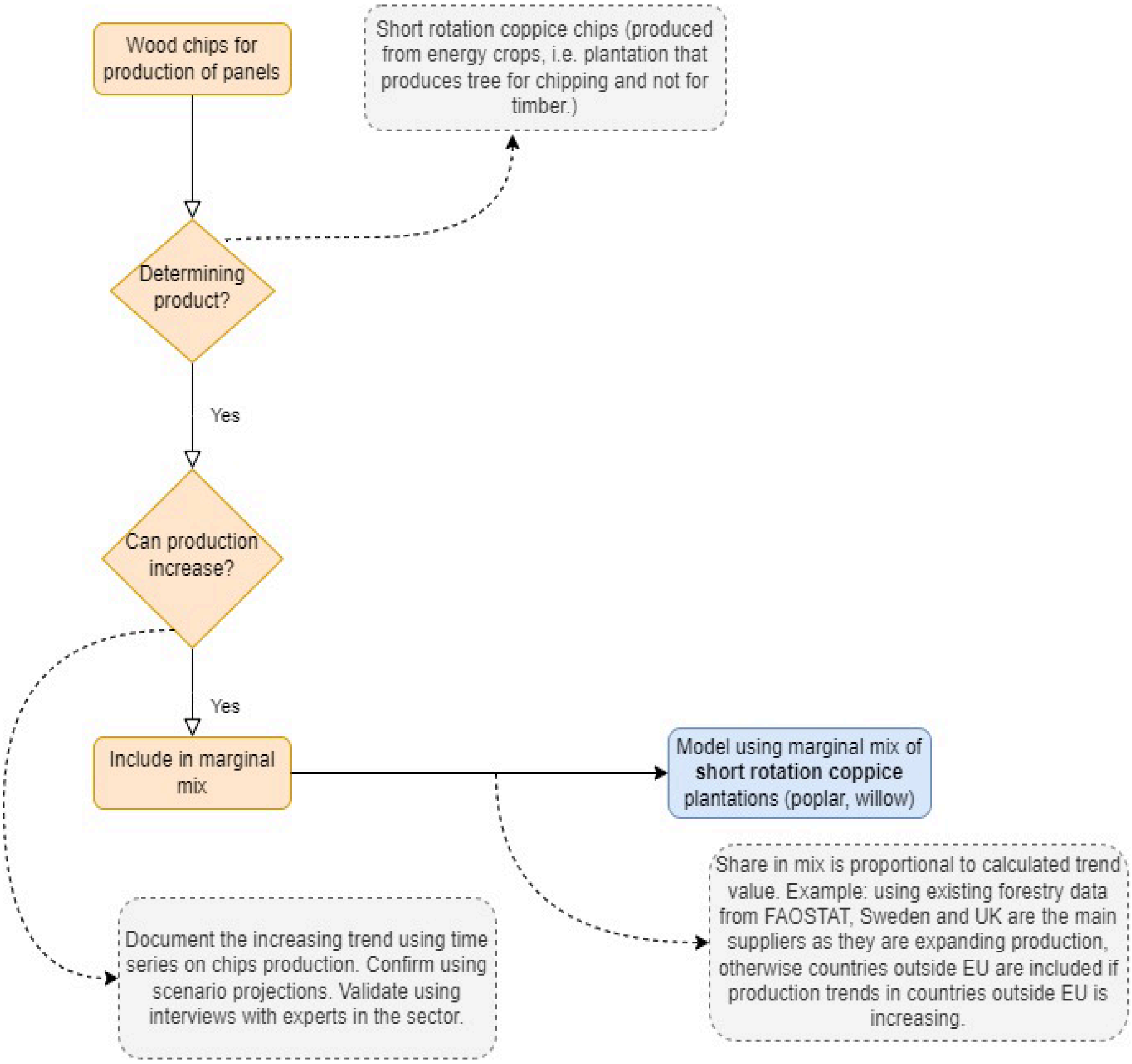

Figure 4 The decision tree applied to understand the feedstock supply for the use of wood chips in construction. Again in this case the feedstock is non-constrained, hence the model needs to identify marginal sources of wood chips from short rotation coppice.

This example is like the previous one but this time we have a different production activity. The challenge remains to have a good method to identify the activities that are affected and what are constrained - in the sense of not being able to expand production - or where the EU capacity is limited, causing a **cascading** effect outside the EU. The affected activities are also those responsible for the impact.

[2] cf. here: https://en.wikipedia.org/wiki/Short_rotation_coppice

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Example 3: chips obtained from residues (from plantation or sawmilling activities). Chips can also be a co-product[3] and this is addressed in this example. One possible case of using a constrained resource could be the use of wood chips to be compressed and glued into wood panel[4]. The flow chart would look like the example below.

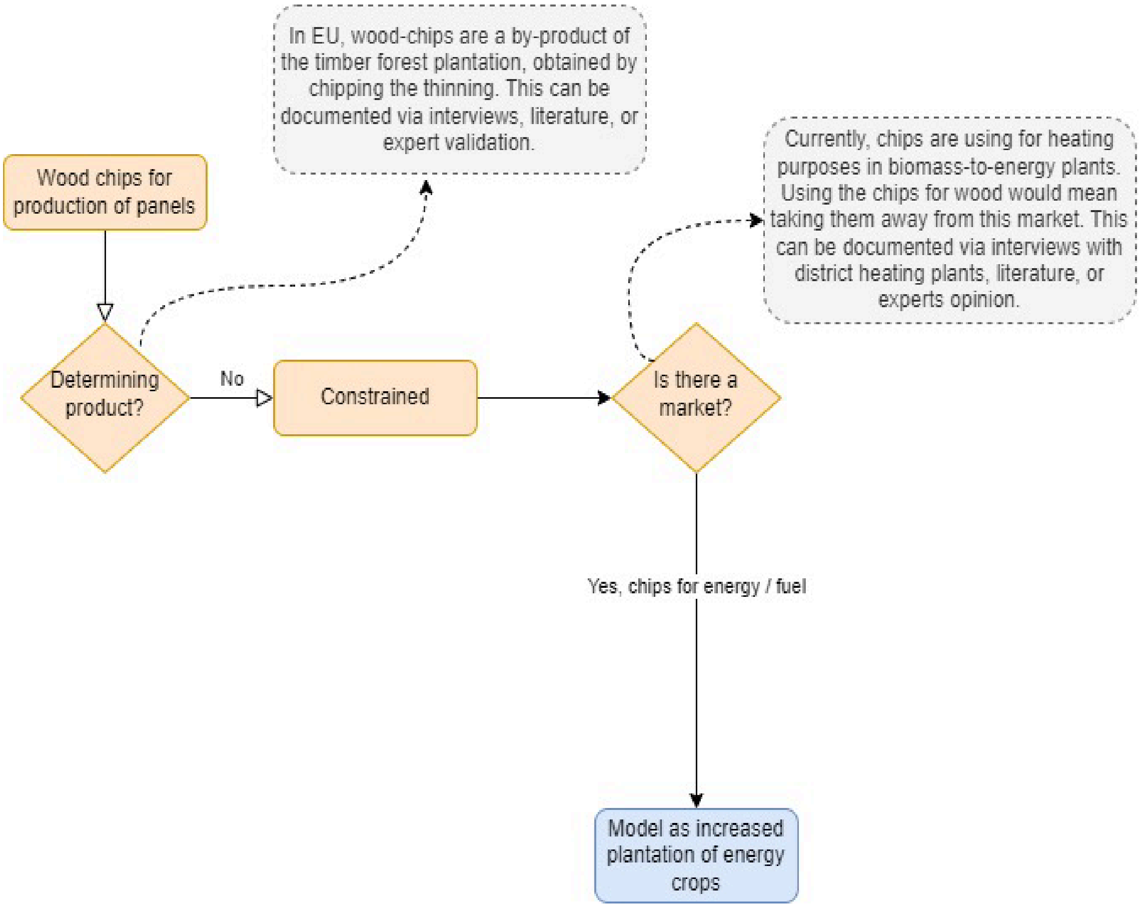

Figure 5 The decision tree applied to understand the feedstock supply for the use of wood chips obtained from thinning of plantations or sawmilling activities. Once identified as constraints with market demand, the increase in demand for these chips in construction sector leads to an increase in demand for alternative feedstock supply in the activities these are currently used (e.g. energy supply from biomass).

This model works when two key assumptions are valid:

- **Assumption 1:** Wood chips are a co-product of the timber forest plantation business. This should be easily documentable. It should also be easily documentable that the revenue for the forest managers comes primarily from the timber, not the chips (therefore they are a dependent co-product).
- **Assumption 2:** Currently, these wood chips are burned into a district heating plant. For example, several Danish district heating plants use chips and specifically residues[5].

[3] Cf. different chips types: https://www.etipbioenergy.eu/value-chains/feedstocks/forestry/wood-chips
[4] Cf. particle board: https://en.wikipedia.org/wiki/Particle_board
[5] For example Hofor https://www.hofor.dk/baeredygtige-byer/fremtidens-fjernvarme/fjernvarmen-bliver-groennere/biomasse-til-amagervaerket/.

Under this logic, let's take the example of a producer of particle board panels that uses chips increases production. When there are not enough chips available because they are currently being used in district heating, the chips being redirected into the higher value products (panels) will result in a shortage of feedstock for the district heating business. In turn the district heating plants will start sourcing chips somewhere else: from dedicated primary plantations. Summing up, the impact associated with producing panels from waste chips is that new plantations will be initiated (with land use, carbon uptake, etc.). Again, this is a **cascading effect** that is logic in theory but difficult to document in practice, besides using evidence from specific cases when available or information purposefully obtained from interviews with those working in the sector that can confirm these mechanisms. This could be considered a model for a **long-term** scenario, where the whole bioeconomy will be highly developed and there will not be much unused resource available, all residual waste streams will be constrained.

Example 4. Chips obtained from residues that are currently **left on ground**. This example is similar to the previous one but with different assumptions. The rationale now is that if these residues, currently left on ground, are valorised into products, then their current degradation on ground is avoided. The model looks very different from the previous case, and therefore, it is important to provide the documentation for these choices and the validity of the assumptions. This could be considered a model for a **short-term** scenario where there still is abundant unused resource available.

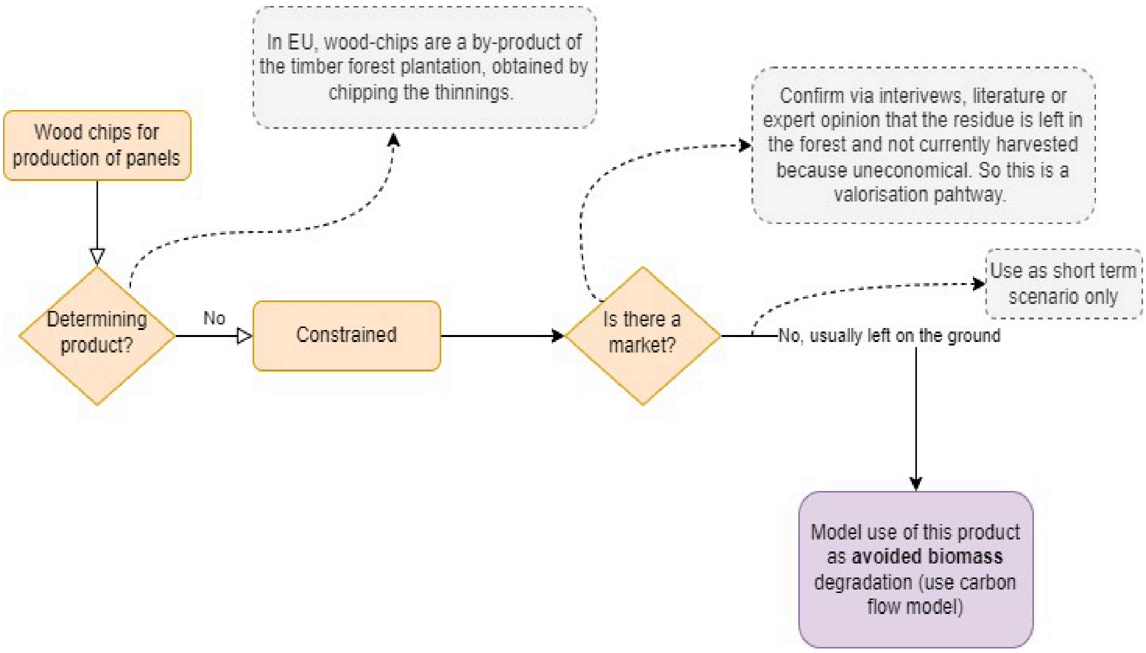

Figure 6 The decision tree applied to understand the feedstock supply for the use of wood chips obtained from forest residues. Once identified as constraints without market demand, the increase in demand for these chips in construction sector leads to avoided effects of current waste management (i.e. avoided biomass degradation as these are usually left on forest floor).

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3. Why a retrospective approach is unfit to model constraints to biomass in LCA.

For completeness we also describe the same flow chart for a retrospective (i.e., attributional) model. The approach is very different because rather than following cause-effect mechanisms and asking questions about cascade effects and current production, the focus is instead on establishing a consensus-based rule for how to partition activities. In the case below we see that it does not matter whether the product is determining or not or what is current production capacity, the assumption is that this activity will provide for the increase in demand for by-products in any case, thus disregarding any potential constrain. The impact of this activity is shared between the product and other co-products of the same production activity.

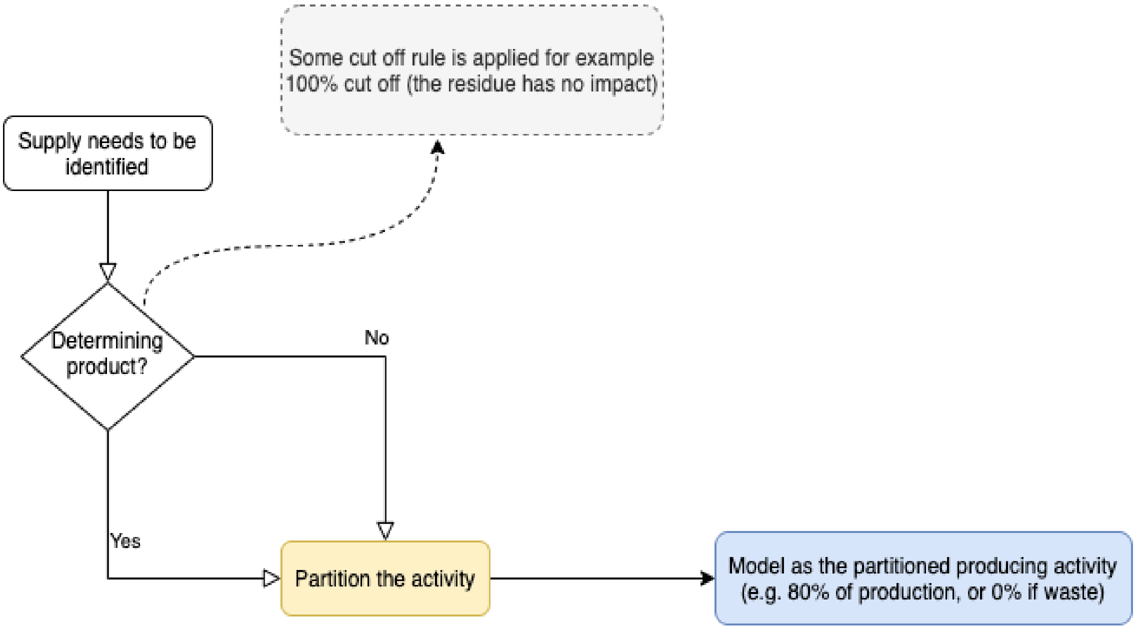

Figure 7 Decision tree applied in attributional modelling.

In the example below (See Figures 8 and 9), what is key is to the allocation rule to use when modelling the system. If a group of stakeholders (e.g., a panel of industry people and academics, as it is the case with the Environmental Product Declaration system and related Product Category Rules) has agreed that waste should not be associated with any environmental burden, then the use of chips is modelled burden free (Figure 8). One might interpret this as if this material "appears out of nowhere" into the model. If instead, the normative rule reached in this consensus is to use the mass as partitioning key, then only a certain percentage of the impact will be attributed to the product (Figure 9). The conclusion is that the attributional approach does not explicitly focus on constraints and is therefore not useful to address the challenges related with production systems which primarily demand for constrained resources in the context of product environmental footprints. In the attributional mindset is rather important to establish shared norms for how to distribute impacts among different products, as this is what is needed to answer the retrospective questions such as *"how can we trace back impacts of the production of this product"*.

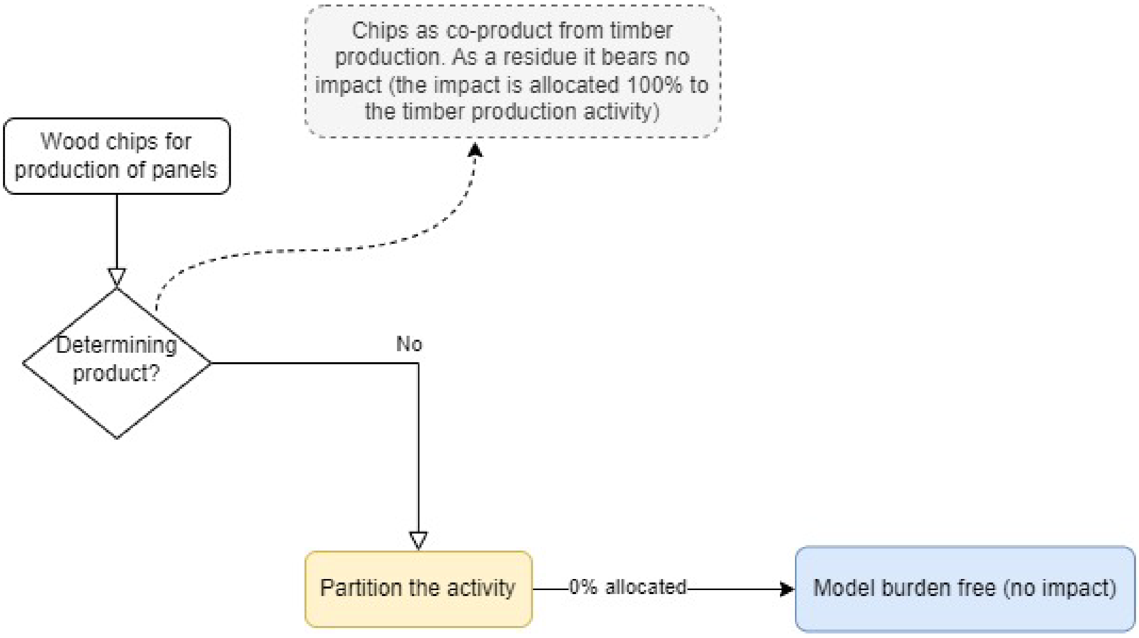

Figure 8 The decision tree for attributional modelling applied to understand the feedstock supply for the use of wood chips in construction, such that, the feedstock supply of wood chips has no market demand (e.g. obtained from forest residues) no impacts are allocated to it.

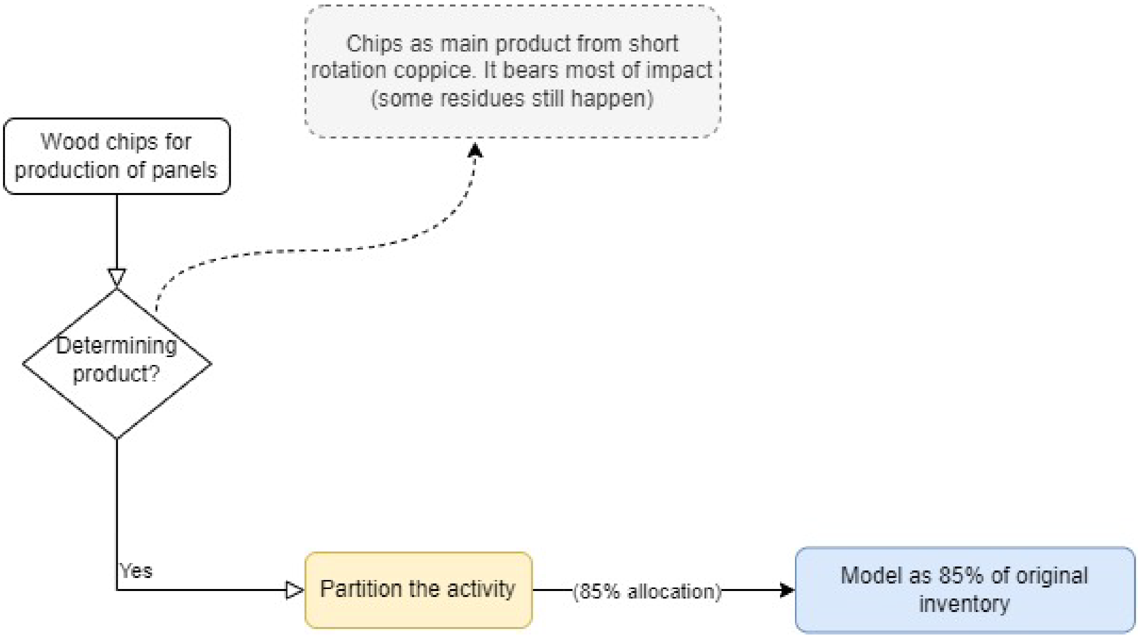

Figure 9 The decision tree for attributional modelling applied to understand the feedstock supply for the use of wood chips in construction such that the feedstock supply of wood chips has market demand, a large share of the impact is attributed to it.

4. Evidence-based approaches to support the modelling choices and strengthen the assessment.

The previous sections presented a series of applications of the same modelling approach, these can be used as guide to study the problem of constraints of biomass **in the context of product environmental assessment** and improvement of environmental performance in industry, which is the context of ALIGNED (the same approaches might not be relevant or as useful in other context for example at macro level).

In short, not all biomasses can be supplied to the extent that we want as some suppliers can either not increase production, because co-products are not their main source of revenue, or the suppliers have limited capacity or are not serving the specific market in case of regional markets (i.e. constraint supply). By defining a mix of unconstrained (marginal) suppliers of biomaterials we study the effect of increasing the demand for these biomaterials, that is driven by the development of an increasing diffusion of bio-based products.

The LCA model design thus depends on the answer to two key questions:

- Knowing whether a biomaterial is a determining or dependent co-product - a relatively straightforward question to answer if the quantities produced and the prices are known, information that producers should have and might be available;

- knowing what suppliers can expand capacity and where - a more difficult question and more complex to answer, sometimes only answerable with high uncertainty. Some common reasons for constraints are shown in Figure 9.

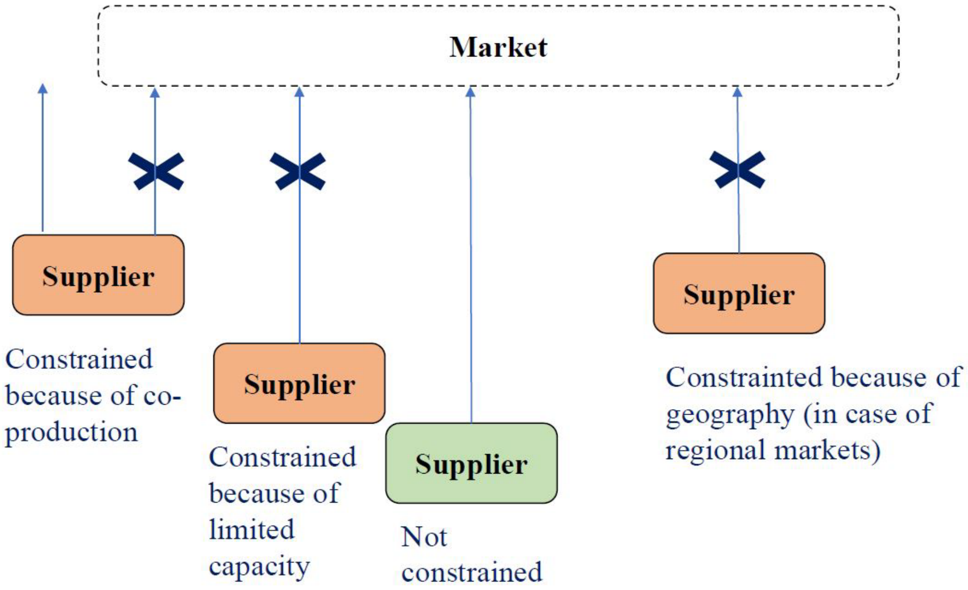

Figure 10 Supply constraints to demands from an existing/ upcoming market can be due to numerous reasons such as limited production capacity, co-product with limited or no market demand or constrained due to geographic location (this could include influence of market policies).

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4.1. Evidence to support modelling choices

The recommended approach in ALIGNED **to support the modelling choices** regarding competition and constraints for biomass using several different types of evidence and scientific methods. These are listed below in order of complexity and validity:

Use transparent assumptions: (Low complexity, low validity) In the absence of information, use assumptions. These should be documented as transparently as possible and explicitly as possible. An example of assumption is "*In the long term all residual feedstock material will be used in production processes of some kind, so any additional demand for waste material or new application will trigger a cascade effect and trigger production of new material*".

Using qualitative information: (Medium complexity, medium validity) Use interviews or information obtained from direct contact with producers of the product, or indirectly from general domain experts (e.g., in forestry), or market experts. See an explicit example in (Ayala et al., in press). Alternatively, use information available from literature such as scientific articles, reports, and news in the media. The target qualitative information to be retrieved should be data that confirm the assumption behind the model, for example expert knowledge on the quantities of residues available currently, their current use and the potential cascading effects of increasing their demand. Other types of expert knowledge or literature data could be e.g. information on the expected growth of the market or the expected suppliers in the future.

Use quantitative information: (high complexity, high validity) Where possible the modelling choices should be supported by quantitative information and data. In this context relevant data are estimates of production quantities for products over time, such as historical time series from existing databases, or future scenarios or projections obtained from other modelling studies in literature. The data should be used in further analysis as for example in (Pizzol and Scotti, 2017) to calculate e.g. the suppliers with the largest production increment over time.

a. Step by step approach to identification of constraints

The recommended approach in ALIGNED **to identify constraints to supply** of biomass is, in two steps:

1) **Identify the co-product constraint**. For example, to answer the question whether the increased use of residues will lead to less residues left on ground or to more plantation from short rotation crops.

Example of approaches relevant in this case:

- When in doubt whether a material is a co-product, use **data on production** costs to identify the determining product. As a rule of thumb determining products are responsible for 80% of the revenue share of a production activity.

- Use **interviews with product manufacturers.** These have detailed, first-hand knowledge on the products of the activity and their markets as well as on the revenue flows for the activity and can confirm whether a product is determining or not as well as cascading effects.

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- Use **scenario data from literature** about the current availability of residues (consider making a sort of merit order or product cost curve figure below, where it is possible to see different suppliers of residues by increasing demand needed).

2) **Identify the production constraint**. Which regions, countries, producers can expand their capacity to meet increasing demand. If we demand more wood, who will supply it? This can be done at different levels of complexity, some indication on the type of data and information below.

Example of approaches relevant in this case:

- Define a **size of the market** using assumptions, information from producers, or knowledge from experts in trade. For example, start with the assumption that the supply of timber products in a Scandinavian country comes primarily from suppliers located in the Nordic Area, and validate such assumption with the opinion of experts in timber or from reports if available. More advanced techniques or models about trade can also be used if available.

- Use **times series data**. Understand which producers show or are expected to show a decreasing or increasing production trend using either historical or forecasted data on the production of different biomaterials (e.g. for different types of forest products or even plantations). Examples are data from FAOSTAT (FAO, 2023) , the JRC (Camia et al., 2018) or other projects on biomass supply forecasting (S2Biom, 2023). These data can be used to select the suppliers showing a positive increment over time and we make a marginal mix based on these data. An example is provided in (Pizzol and Scotti, 2017) or here[6] for energy (same methodology). The single inventories of wood production in a specific region can then be obtained using a dedicated carbon flow model (also part of ALIGNED modelling framework). The problem with time series data is that when we use the historical trends, we don't know if they are representative of the future. When we use scenarios made by others, we introduce some uncertainty depending on what is the methodology for making the scenarios. Another issue is that predictions can only be validated ex-post (after time has passed) while we need to provide the decision support now. The approach recommended in the ALIGNED project is to make sure that we use the best available knowledge and data at the time of making the decision.

[6] https://consequential-lca.org/clca/marginal-suppliers/the-special-case-of-electricity/example-marginal-electricity-in-denmark/

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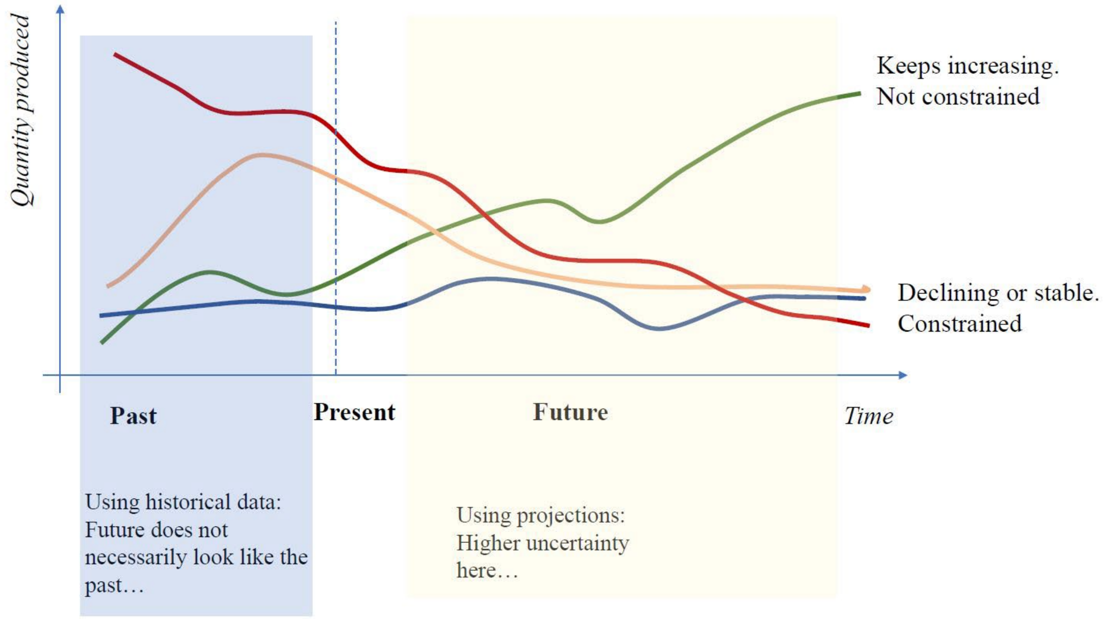

Figure 11 Production trends across years can indicate increasing or declining production capacities over the years. Increasing capacities are considered unconstrained and included in the market mix. Uncertainties related to using historical or future projections may occur.

- Use **production costs.** When available, data on production costs can be used to estimate a supply curve showing the capacity of each supplier to meet different levels of demand. The approach is for example illustrated in (Thonemann and Pizzol, 2019). The increase in demand for a product contributes to an increase in production costs. In the short-term small-scale suppliers may be able to increase capacity. However, with increasing demand, small scale suppliers may reach overall capacity thus remaining constant, hence large-scale suppliers will then form the marginal mix.

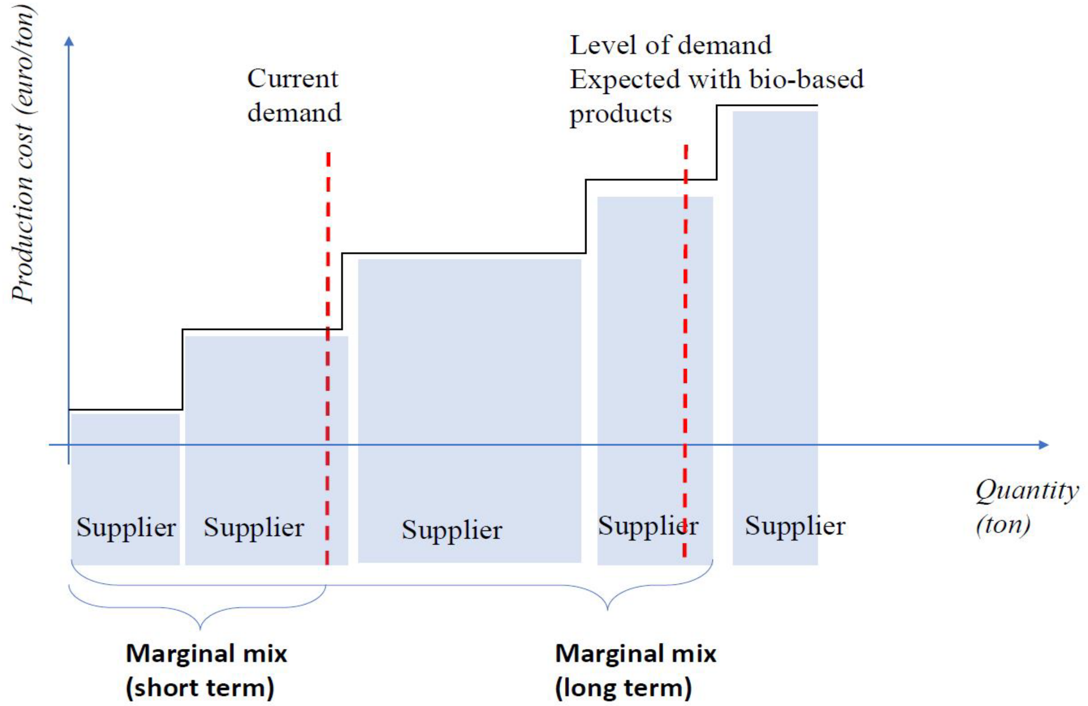

Figure 12 Production costs can be used to develop marginal supply mix.

Conclusion

In conclusion, this report delves into the challenges surrounding the increasing demand for bio-based products and the ensuing competition for biomass supply. By offering a methodological framework and specific recommendations, it equips practitioners with the necessary tools to navigate the challenges of increasing biomass competition.

The report underscores the limitations of retrospective (attributional) modeling in capturing the cascading effects and constraints associated with increased demand for biomass. Through detailed decision trees and examples, it shows how practitioners can identify constraints and marginal suppliers, thereby enhancing the robustness of LCA studies in the bio-based sector.

Furthermore, the report emphasizes the importance of evidence-based approaches to inform modeling choices and strengthen assessments. By integrating transparent assumptions, qualitative information, and quantitative data, practitioners can develop more comprehensive models that reflect real-world dynamics and uncertainties.

In essence, this report serves as a valuable resource for researchers, policymakers, and industry stakeholders seeking to improve the environmental performance of bio-based sectors. By promoting a holistic understanding of biomass competition and constraints, it paves the way for more informed decision-making and sustainable practices in the transition towards a non-fossil bioeconomy.

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