Short communication

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Developing BioMAT: A new conceptual framework to model the market of bio-based materials in the EU

The supply and use of bio-based products may yet shape the future, contributing to the achievement of broader objectives such as climate neutrality, circularity, and sustainability. Reducing dependency on non-renewable resources, and substituting fossil-based resources with biomass by way of a transition to a sustainable industrial – and especially chemical – sector, represent important challenges. To be able to understand what may be desirable pathways to a 'green' chemical sector, insights on the upcoming needs of biomass for the EU bio-based industry are required, together with information about its availability and the way it is produced. However, there is a lack of methodologies and quantitative tools capable of assessing and anticipating potential developments in the EU bio-based markets. To provide an early theoretical basis for the upcoming modelling of supply chains of the bio-based materials market, this short communication presents the conceptual framework underlying the BioMAT (Bio-based MATerials) model, developed in the course of the EU H2020 BioMonitor project.

Keywords: Bioeconomy, bio-based products, biomass feedstock, EU markets outlooks, partial-equilibrium (PE) modelling, BioMAT.

JEL classifications: Q01, Q02, Q11.

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Introduction

Contemporary challenges such as climate change, the unsustainable rhythm at which natural resources are deployed, the generation of waste or the provision of healthy food for all ought to be a key preoccupation for policymakers. In general terms, these challenges demand for a new paradigm in which all participants in the food system play more 'sustainable' roles. Thinking about sustainability, one can think of the model proposed by Raworth (2017), i.e. the so-called 'doughnut model' which puts together environmental and socio-economic challenges in a coherent and balance manner. As pointed by Raworth (2017), 'humanity's 21st century challenge is to meet the needs of all within the means of the planet'. This statement can be translated into the 'doughnut' which is defined by an outer circle representing the environmental ceiling, as well as an inner circle which is defined by social foundations as determined in the context of the Sustainable Development Goals (SDGs).[1] An interesting aspect of the 'doughnut model' is the richness of elements that it integrates: housing, gender equality, food, income, biodiversity, climate change, air pollution, land conversion, etc. According to Raworth (2017), the target should be on 'staying within the doughnut' rather than pursuing economy growth. In other words, the focus should be on staying within 'the safe and just space for humanity' which reflects a 'sustainable' position for the entire economic system.

Teodorescu (2015) suggests that 'sustainable development is meant to be the summation of economic, environmental and social considerations for the present and especially for the future'. Along the same lines, Dyngeland *et al.* (2020) emphasise that there is a need for further analysis of the interactions between the social and environmental outcomes of sustainable development policies, this being particularly relevant when assessing progress towards achieving the SDGs. Moreover, Chavarria *et al.* (2020) indicate that the bioeconomy is an important option when working towards the achievement of the SDGs. In particular, the substitution of fossil-based resources that are used for energy supply and industrial purposes with bio-based ones could contribute towards making the economy more sustainable and efficient from a resource utilisation perspective. The same source also highlights the importance of the bioeconomy for achieving objectives linked to food security and nutrition, health, and well-being, as well as clean water and sanitation.

As defined by European Commission (2012, 2018), the bioeconomy is 'the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling industrial technologies, along with local and tacit knowledge'.[2, 3] European Commission (2013) also indicates that a transition towards a bio-based economy is required to provide a suitable response to problems such as food security, energy security, the high dependence on fossil-based resources, and the increasing demand of biological sources for production of bio-based materials, among others. This transition is also the appropriate response to sustainability concerns related to GHG emissions, excessive waste,

[1] See Luukkanen *et al.* (2021) for an application quantifying the doughnut economy with the sustainability window method in the case of Thailand.

[2] Further details are available at: https://ec.europa.eu/research/bioeconomy/pdf/bioeconomycommunicationstrategy_b5_brochure_web.pdf.

[3] Ronzon *et al.* (2020) estimate that the bioeconomy generated around €614 billion of value added in 2017 which is equivalent to 4.7% of the EU27 GDP, while creating jobs for 9% of the EU27 workforce.

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environmental sustainability of primary agriculture, increasing competition for land, etc. To really contribute to better climate conditions, biomass must be produced along two key sustainability principles, which are mainly the avoidance of: (i) LULUC effects, e.g. deforestation; and (ii) competition with biomass usages for food. In the action plan of EC's Bioeconomy Strategy (European Commission, 2018), it is mentioned that the development of the bioeconomy should be monitored and analysed to understand if multiple targets develop in the right direction and at sufficient speed. However, there is a lack of methodologies and quantitative tools which permit to assess and anticipate the potential developments of the EU bio-based markets. Against this background, this short communication aims at expanding the existing body of knowledge by presenting a consistent conceptual framework for analysis of the value chain of bio-based materials in the EU and its Member States. This conceptual framework constitutes the theoretical underpinnings of the BioMAT (Bio-based MATerials) model, developed over the course of the EU H2020 BioMonitor project.[4]

Literature review

When looking at the development of the bio-based economy and its potential expansion, the demand side is due some consideration. This is the case since consumers are not fully aware about the availability and characteristics of the bio-based choices that are at hand when trying to adopt a 'more sustainable' consumption pattern. To make the point, we refer to a comprehensive study (Hempel *et al.,* 2019) on the societal acceptance of a bio-based economy in Germany. Hempel *et al.* (2019) show that consumers generally have a positive attitude towards the consumption of bio-based products. However, citizens seem to need more information and background knowledge to make their decisions, asking the relevant support from policymakers. Moreover, Sijtsema *et al.* (2016) look at individuals' perceptions regarding the broad concept of 'bio-based' and a particular selection of bio-based products. This piece of research has revealed that the concept of 'bio-based' is still an unfamiliar notion for many. Individuals' perceptions regarding 'bio-based' are quite mixed. The concept was related to both positive and negative environmental aspects, which gives some evidence on the lack of knowledge and information that consumers have. All these findings emphasise the need for further public interventions to facilitate the adoption of new consumption habits, as well as the development of further bio-based goods.

Therefore, for bioeconomy potentials to materialise, and apart from the technical progress on the supply side, consumer behaviour needs to change so that the transition from fossil-based products to their bio-based alternatives happens. Hence, certifications, green premiums, awareness-raising campaign, subsidies, etc. are among the tools that policymakers have at their disposal to facilitate this transition.[5] As Stern *et al.* (2018) have emphasised, it is important to make the process as inclusive as possible, the consumer being a central actor that needs to be mobilised. This process should involve all societal actors in a bottom-up manner so that they can engage with the concept of bioeconomy and contribute to the process. Focusing on green premiums and consumer behaviour, Partanen *et al.* (2020) explore the willingness of consumers to pay an additional price for the bio-based alternatives to fossil-based choices. The study concludes that bio-based options can receive green premiums that extend beyond energy applications.

Nevertheless, Diakosavvas and Frezal (2019) point out that the expansion of the bioeconomy *per se* is not intrinsically sustainable. All the participants in the bioeconomy should be aware of the existence of economic, social, and environmental trade-offs that cannot be avoided. Diakosavvas and Frezal (2019) perfectly illustrate the complexity surrounding the notion of 'bioeconomy' when concluding that 'determining the most cost-efficient use of biological and other resources to meet food, feed, fuel and fibre needs is a major challenge for private and public policy decision makers', the bioeconomy is a multidimensional system which should be studied from all angles, i.e. economic, societal, environmental, etc. Hence, its analysis needs an integrated approach comparable to the 'food systems' framework that is increasingly being used to understand and model the 'traditional' agri-food sector.[6] Calicioglu and Bogdanski (2021) indicate that the emphasis should not be on measuring how the bioeconomy develops but on measuring its sustainability. In particular, the authors also suggest that the monitoring and evaluation of the bioeconomy have coupling potential with SDG reporting particularly on the fields of biodiversity conservation, waste reuse, gender equality, inclusiveness, and international cooperation.

A final remark in terms of the gaps identified in the existing body of literature is needed. Chavarria at el. (2020) point out that there is an important knowledge gap when indicating that the transition towards a bio-based economy requires: '(i) a broader agreement on guiding principles for global bioeconomy policy making; (ii) a framework of credible bioeconomy indicators; and (iii) an effective bioeconomy knowledge management platform.' Despite the consensus around the relevance of these elements, these three aspects are important areas in which the available statistical sources and frameworks of analysis seem to lag behind. All these observations highlight the 'value added' of presenting the conceptual framework underlying BioMAT to a broader audience.

A conceptual framework for representing the EU bio-based commodity markets

Functional specification

When sketching the 'building blocks' that make up the bioeconomy, e.g. bio-based chemicals, bio-based solvents, etc., researchers should focus on understanding the key drivers of production, imports, exports, uses and prices of bio-based products (as well as the determinants

[4] See: https://biomonitor.eu/.

[5] Along the same lines, Diakosavvas and Frezal (2019) suggest that further development of the bioeconomy would require a combination of technology-push and market-pull policy initiatives that expand the demand for bio-based products. This increase in demand should happen at both public and private levels.

[6] See Gonzalez-Martinez *et al.* (2021) for further discussion on the food system approach in the case of the agri-food sector.

of their fossil-based counterparts).[7] For each of these ‘building’ blocks, there are four dimensions that need to be considered: countries, product applications, biomass feedstock types, and time.[8] In terms of the country dimension, this framework (and subsequently, BioMAT) considers all EU27 Member States and the United Kingdom as individual regions.[9] In addition, a ‘Rest of the World’ region is also modelled in order to ‘close’ the system. Turning to the product-application dimension, it distinguishes the following chemical applications: (i) chemical platform products; (ii) solvents; (iii) polymers for plastics; (iv) paints and oils; (v) surfactants; (vi) lubricants; (vii) adhesives; (viii) cosmetics; (ix) pharmaceuticals; (x) biofuels; (xi) food & feed; (xii) building material; (xiii) agrochemicals; (xiv) manmade fibres; and (xv) other products. In addition, the framework accounts for the following biomass feedstock types: (i) starch; (ii) industrial sugar; (iii) industrial plant oils; (iv) wood lignocellulose; (v) agricultural lignocellulose; (vi) animal biomass, (vii) aquatic biomass; and (viii) other forms of biomass. For a comprehensive modelling, it is important to consider future developments of the total market of specific products, separately representing fossil-based and bio-based alternatives. Where the time dimension is concerned, a period ending in 2030 is sufficient for a modelling tool to deliver medium-term insights, although it can also consider a longer-term horizon.[10]

Keeping in mind the categories mentioned above, Table 1 provides an overview of the key relations (equations and identities) and determinants (variables), which together comprise the present framework. As has already been advanced, this specification is used as the basis for estimating the equations that comprise the BioMAT model, covering bio-based (BCH) applications, fossil-based (FCH) alternatives and the total (TCH) market.

Table 1: Key equations/identities to be estimated when modelling the bioeconomy.

Supply equations for a given chemical application K			
Total supply chemical application *K*	$TCH\_S_{K,CC,T}$	=	$f(pf_{K,CC,T}, V_{K,CC,T})$ *pf = price indicator of application K* *V = vector of exogenous variables which have an impact on supply, e.g. policy variables, trend*
Share of bio-based formulations over total supply	$shBCH\_S_{K,CC,T}$	=	$f(cdr_{K,CC,T}, fcr_{F,K,CC,T}, V_{K,CC,T})$ *cdr = total production cost ratio of bio-based and fossil-based application K* *fcr = efficiency ratio to convert biomass feedstock into application K* *V = vector of exogenous variables which have an impact on bio-based supply share for application K*
Bio-based supply	$BCH\_S_{K,CC,T}$	=	$TCH\_S_{K,CC,T} \cdot shBCH\_S_{K,CC,T}$
Fossil-based supply	$FCH\_S_{K,CC,T}$	=	$TCH\_S_{K,CC,T} - BCH\_S_{K,CC,T}$
Demand equations for a given chemical application K			
Total demand chemical application K	$TCH\_D_{K,CC,T}$	=	$f(gdpc_{K,CC,T}, V_{K,CC,T})$ *gdpc = income per capita* *V = vector of exogenous variables which have an impact on demand, e.g. consumer preferences, policy variables, trend*
Share of bio-based formulations over total demand	$shBCH\_D_{K,CC,T}$	=	$f(pxr_{K,CC,T}, V_{K,CC,T})$ *pxr = price ratio between bio-based and fossil-based chemical application K* ($pb_{K,CC,T} / pf_{K,CC,T}$) *V = vector of exogenous variables which have an impact on bio-based demand share for application K*
Bio-based demand	$BCH\_D_{K,CC,T}$	=	$TCH\_D_{K,CC,T} \cdot shBCH\_D_{K,CC,T}$
Fossil-based demand	$FCH\_D_{K,CC,T}$	=	$TCH\_D_{K,CC,T} - BCH\_D_{K,CC,T}$

7 The experience gained in the case of modelling the agro-food value chains in AGMEMOD (Agriculture Member State Modelling) is a source of inspiration when thinking about the general structure of this framework and the interaction among key elements such as production, consumption, trade, etc. Further details on the AGMEMOD model are available at: https://agmemod.eu/.

8 The combination of these four dimensions constitutes the so-called ‘modelling space’.

9 The level of detail that each country model has is highly dependent on the availability of data in the existing statistics.

10 The period is extendable to 2050 when thinking of simulating long-term scenarios.

'Closing' the market		
TCH net exports	$TCH\_NEX_{K,CC,T}$ =	$TCH\_S_{K,CC,T}$ - $TCH\_D_{K,CC,T}$
BCH net exports	$BCH\_NEX_{K,CC,T}$ =	$BCH\_S_{K,CC,T}$ - $BCH\_D_{K,CC,T}$
FCH net exports	$FCH\_NEX_{K,CC,T}$ =	$FCH\_S_{K,CC,T}$ - $FCH\_D_{K,CC,T}$
Biomass feedstock supply for material use		
Supply of feed type *F*	$BM\_S_{F,CC,T}$ =	*As calculated by the AGMEMOD model for agricultural resources; EFI-GTM for wood; S2Biom for residues*
Biomass feedstock demand for material use		
Domestic use of feed type *F* by bio-based chemical product *X* belonging to application *K*	$BM\_D^x_{K,F,CC,T}$ =	$BCH\_S^x_{K,F,CC,T} \cdot fcr^x_{K,F,CC,T} \cdot shf^x_{K,F,CC,T}$ *BCH_S = supply of feed type F for conversion into a bio-based product X belonging to application K* *fcr = feedstock conversion rate between use of bio-mass feedstock type F and the bio-based product X belonging to application K* *sfh = share of feedstock type F in total feedstock use of bio-based product X within application K*
Biomass feedstock net exports	$BM\_NEX_{F,CC,T}$ =	$BM\_S_{F,CC,T} - BM\_D_{F,CC,T}$ *NB.* $BM\_S_{F,CC,T}$ *and* $BM\_D_{F,CC,T}$ *are calculated by aggregating feedstock supply and domestic use for all products included in all the different applications*
Price equations		
Fossil-based application producer price	$pf_{K,CC,T}$ =	$f(kpf_{K,CC,T}, V_{K,CC,T})$ *kpf = EU price indicator of fossil-based application* *NB. If CC is the country 'setting' the price at EU level, kpf is replaced with a world market price indicator and the self-sufficiency rate of the EU for that chemical application* *V = vector of exogenous variables which have an impact on national price, e.g. oil price developments* *NB. If CC is the country 'setting' the price at EU level, V includes exchange rates and trade policies*
Bio-based application producer price	$pb_{K,CC,T}$ =	$f(kpb_{K,CC,T}, V_{K,CC,T})$ *kpb = EU price indicator of bio-based application* *NB. If CC is the country 'setting' the price at EU level, kpb is replaced with a world market price indicator and the self-sufficiency rate of the EU for that chemical application* *V = vector of exogenous variables which have an impact on national price, e.g. oil price developments* *NB. If CC is the country 'setting' the price at EU level, V includes exchange rates and trade policies*
Price biomass type *F* (national price indicator of feedstock)	$pbm_{F,CC,T}$ =	$f(kpbm_{F,CC,T}, V_{F,CC,T})$ *kpbm = price of the feedstock in the country that is the key player within the EU* *NB. If CC is the country 'setting' the price at EU level, kpbm is replaced with a world market price indicator and the self-sufficiency rate of the EU for that feed-stock type* *V = vector of exogenous variables which have an im-pact on national feedstock prices, e.g. CAP measures* *NB. If CC is the country 'setting' the price at EU level, V includes exchange rates and trade policies*

Note: **K =** chemical products: platform chemicals, solvents, polymers for plastics, paints and oils, surfactants, lubricants, adhesives, cosmetics, pharmaceuticals, food & feed, building material, agrochemicals, manmade fibres, and other products. **T =** year, 2010-2030 (or 2050). **CC =** individual EU27 Member State, the UK and the Rest of the World (RoW). **F =** feedstock type, e.g. starch, industrial sugar, industrial plant oils, wood lignocellulose, agricultural lignocellulose, animal biomass, aquatic biomass, and other biomass. **I =** culture group, e.g. grains, oilseeds and root crops. **X =** product types, e.g. polymers for plastics includes polyacetals, other polyethers and epoxide resins, in primary forms; polycarbonates, etc.
Source: own composition.

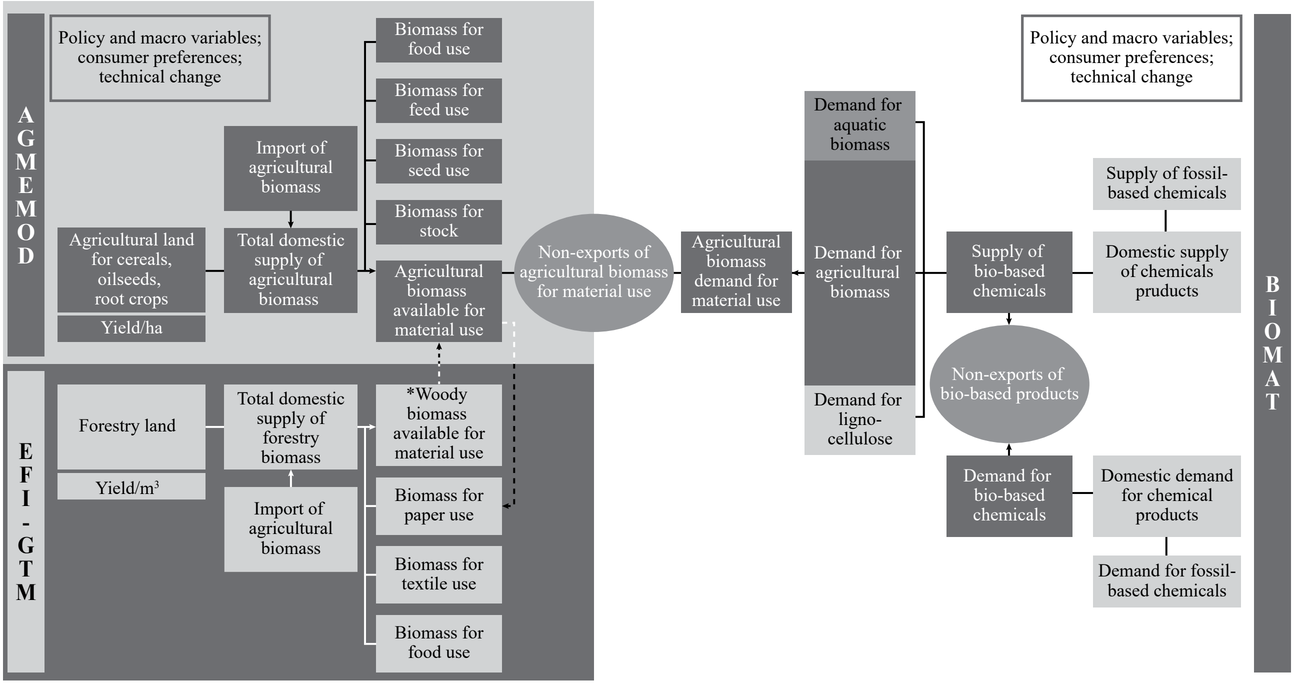

Figure 1: Integrated modelling use of AGMEMOD, EFI-GTM and BioMAT.

* For industrial sugar.

Source: own composition

The actual ‘construction’ of the BioMAT model will involve the estimation of more than 8000 relationships following the specification presented in the table above. A Cobb-Douglas (Cobb and Douglas, 1928) specification is used for the equations that deliver the share of bio-based formulations over the total market. To illustrate this, a generic example is provided below, which represents the case of the relative market share of a given bio-based application:

$$shBCH\_S = a \cdot cdr^{b} \cdot fcr^{c} \cdot T^{d} \quad (1)$$

with *a* being the intercept; while *b*, *c* and *d* are the relevant elasticities for the cost ratio, *cdr*, efficiency ratio, *fcr*, and the trend variable, *T*.

Further considerations

Since models are by definition a simplification of reality (van Tongeren *et al.,* 2001), there is also room for model collaboration when thinking of modelling the bioeconomy according to this framework (see e.g. Gonzalez-Martinez *et al.,* 2021). A direct ‘hard’ linkage (Wicke *et al.,* 2015) has been established between BioMAT and the existing AGMEMOD (Agricultural Member State Modelling) model; while it has a ‘soft’ linkage with the global forest and wood-based product model EFI-GTM (Figure 1).[11] The first linkage allows AGMEMOD to deliver projections on available raw feedstock for food and feed processing and industrial uses, while BioMAT feeds back the required biomass feedstock required in the material industry. BioMAT also connects to EFI-GTM by giving insights into the amount of wood lignocellulose available for material use in bio-based chemical products and feeds back the use of starch for paper production to EFI-GTM. Additional model linkages could be developed on an *ad doc* basis for the simulation of alternative scenarios.

Conclusions

A pressing issue on the policy agenda is how to monitor and assess the expansion of the bioeconomy, as well as the effectiveness of the related public interventions. The need for evidence-based policy making in this area can only be satisfied by the development of quantitative tools for analysis that represent the key elements of the supply and demand sides of the bioeconomy. Ideally these tools should also provide forward-looking insights that permit ex-ante policy assessment. As an interim step towards the ‘construction’ of a fully operational quantitative tool, i.e. the BioMAT model, there was a need for developing a conceptual framework identifying the most relevant elements and interactions of bio-based value chains, as concluded from the gap analysis presented in Lovrić *et al.* (2020). Sharing the ‘conceptual’ outcomes of the initial stages of the development of the mentioned model is of general interest since it could inspire upcoming modelling exercises that focus on the potential development of bio-based products and their contribution to achieving societal goals (like reducing dependence on non-renewable resources).

To sum up, the proposed framework explains the demand for bio-based products by means of consumer preferences and the relative prices of bio-based and fossil-based products. The supply of bio-based products explains the need for biomass feedstock, determined by the efficiency to convert biomass into bio-based chemicals, and the relative production costs of bio-based and fossil-based products among

[11] For further details on these two models, see: AGMEMOD (https://agmemod.eu/); and EFI-GTM (https://efi.int/sites/default/files/files/publication-bank/2018/ir_15.pdf).

others. This framework is flexible enough to account for (current and foreseen) policy instruments that could potentially influence the future development of the EU bio-based chemical markets, e.g. direct interventions that could affect the prices of bio-based and fossil-based materials, and therefore, change consumer preferences. When the BioMAT model is fully operational, it will also allow for the simulation of the potential impacts of interventions that mitigate climate change such as the reduced use of pesticides and fertilisers adopted in the new Common Agricultural Policy (CAP), or measures that set a CO_2 price on unsustainable production methods. In short, this framework makes it possible to assess the effects of alternative pathways of bio-based chemical markets, and thereby creates new opportunities for analysing the development of the market for bio-based materials, as well as how they contribute to achieving sustainable goals.

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