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Boosting Biowaste Valorisation—Do We Need an Accelerated Regional Implementation of the European Law for End-of-Waste?

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Abstract: The valorisation of municipal and household biowaste as a relevant component of the EU's Circular Economy Strategy is currently under discussion. However, there are several legal, technical and economic challenges associated with biowaste valorisation. This paper aims to pinpoint factors affecting biowaste supply chains using the PESTEL+I method and stakeholder workshops. Our analysis focuses on the macro-environment of an integrated biowaste conversion and valorisation concept in the region of Wallonia, Belgium. One key influencing factor is the EU's legal framework on waste, which describes the end-of-waste status and defines criteria for biowaste reuse. While the analysis shows that EU regulations support biowaste valorisation, its transposition into national and regional law is lagging behind. The technological development of biowaste concepts might be hampered and many questions related to the marketisation of bio-based products remain unanswered. We therefore suggest that legal procedures for biowaste management have to be facilitated at the regional level. The region of Wallonia should establish a category for biowaste that would include standardized procedures for biowaste valorisation and products. It is essential that such regional barriers be overcome to establish the necessary cooperation with local stakeholders and to transfer biowaste supply chains to the market.

Keywords: biowaste valorisation; circular bioeconomy; policy; supply chain; EU; stakeholders

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1. Introduction

The transition from fossil-based economies to sustainable and circular bioeconomies is crucial to meet the EU's climate targets and Green Deal [1]. For the purpose of this study, the bioeconomy is defined as the use of renewable biological resources to produce food, materials and energy [2]. Sustainable bioeconomies can reduce dependence on fossil resources, mitigate land degradation, and support local and rural development [2]. However, the establishment of bioeconomies does not lead to sustainable outcomes per se, as these can be tied to unsustainable biomass cultivation or biomass imports [3,4]. The valorisation of biowaste through cascading use represents a smart option to support sustainable biomass supply [5,6]. Furthermore, biowaste treatment, collection and conversion can positively contribute to climate change mitigation, as biowaste is one of the primary causes of greenhouse gas emissions in landfills [5].

Urban areas are biowaste production hotspots. Cities around the world produce 1.3 billion tonnes of solid waste each year. Organic residues make up roughly half of that amount, totalling 650 million tonnes annually [7]. The recovery of organic waste streams could lead to large material savings and CO_2 emission reductions of up to 260 million tonnes per year (400 kg CO_2 per tonne of organic waste) [8]. The potential use of biowaste as a biomass feedstock is, however, underutilized [9]. Best practices show that biowaste valorisation strategies, implemented at the local level, contribute to sustainable agriculture practices and to the creation of local jobs [9].

There are already applications of bio-waste in composting [10]. In addition, it can be used as an additive in more sustainable cement production or by various carbonization processes such as torrefaction or pyrolysis [11,12]. Moreover, a variety of biowaste streams are suitable for producing bio-based goods, including industrial residues, municipal wastes, and agricultural by-products, which were previously considered challenging and expensive to handle and treat [13]. Currently, the availability of biowaste is heterogeneously distributed across EU countries (Figure 1) [14,15]. The theoretically available potentials of wastes and residues for the 27 EU member states from 2010 to 2020 were estimated to range between 21 to 37 million tonnes [FM/a] of biogenic municipal waste, 87–111 million tonnes [FM/a] of industrial residues and 276–337 million tonnes [FM/a] of agricultural by-products [15,16].

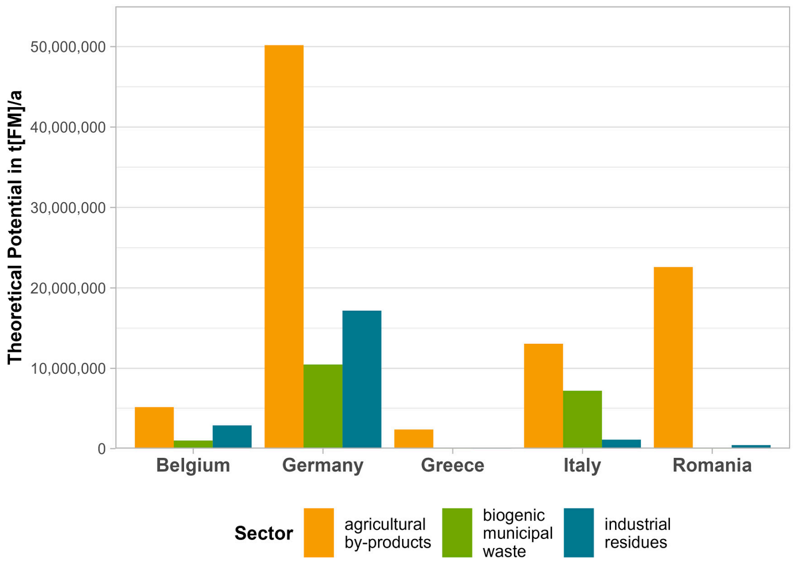

Figure 1. Theoretical biomass potential from wastes and residues in Belgium, Germany, Greece, Italy and Romania (2020, NUTS-0) [15].

More recently, the use of biomass as a material has become increasingly relevant for the production of bio-based products. In this context, biowaste valorisation can play a key role in reducing dependency on fossil-based resources as it can promote the production of bio-fertilizers, bio-plastics, food, pharmaceuticals and cosmetics [17]. The EU Circular Economy Strategy envisages the valorisation of biogenic residues as a milestone for the establishment of circular economies in Europe [18]. The EU Bioeconomy Strategy proposes new pathways for biowaste valorisation, namely the production of platform chemicals (short chain and medium chain carboxylic acids, SCCA and MCCA) for bio-based plastics such as polyhydroxyalkanoates (PHA), the extraction of microbial proteins as a food additive, the extraction and recovery of medical ingredients and the recovery of fibres [9]. The EU Bioeconomy Strategy's latest report suggests that, while there are only a few bio-based chemical platforms, their applications are expected to grow significantly in the future and represent a valid alternative to fossil-based chemicals [9,19]. Biowaste is already used in many countries, mainly as part of recycling (compost) or energy generation processes. In order to unlock the potential for biowaste valorisation, there needs to be financial incentives. This would make new pathways in the market attractive and more competitive for interested stakeholders [20].

This paper is part of the Horizon 2020 research project, CAFIPLA [21], which examines biowaste valorisation based on the collection and pre-treatment of heterogenic municipal biowaste and its conversion to bio-based products (SCCA, fibres) using an innovative and cost-effective technology (Figure 2) [17,20]. The region under examination is Wallonia in Belgium. According to the government of Wallonia, compostable organic waste or biofermentable waste represents 41% of mixed household waste in Walloon households [22,23]. Therefore, these biowaste streams, which are currently not being specifically collected, have a considerable potential. Annual mixed household waste is estimated to be, on average, 523 kg/person in Wallonia and 500 kg/person in Europe, with notable differences among EU member states [23]. Building on the biowaste valorisation potential in the region of Wallonia, this paper aims to highlight the factors influencing the implementation of regional supply chains based on a combined carboxylic acid platform (CAP) and fibre recovery platform (FRP) in order to valorize biomass into biochemicals, bioproducts, feed and biomaterials in Europe. To achieve this, a detailed analysis was conducted which examined macro-environmental factors such as political, economic, social, technological, environmental, legal and infrastructural aspects. This analysis was combined with a stakeholder network analysis to specify key barriers and enablers for local stakeholders. The final goal was to derive recommendations to boost implementation of biowaste-based product value chains in Wallonia and other European markets.

Table 1. Stakeholders involved in a biowaste supply chain.

Stakeholder Group	Description	ID (Figure 2)
Feedstock suppliers	Waste treatment, waste handling and recycling company	1
	Public waste disposal service	2
	Municipality	3
	Food industry, stores and producers	4
	Agricultural cooperatives	5
Competitors for feedstocks	Biomass treatment and valorisation	6
	Waste incineration	7
	Composting industry	8
Plant operators	Regional economic development	9
	Waste treatment, waste handling & recycling company	10
	Public waste disposal service	11
	Agricultural cooperatives	12
	Biogas plant operators	13
Service providers	Incubators, regional innovation hub	14
	Funding service for European research and innovation	15
	Environmental consulting company	16
	European Commission	17
Society, research	Research institute agro-food/environment	18
	Research institute for sustainable chemistry and environment	19
	Research institute for agricultural engineering and bioenergy	20
	Institute for technological research	21
	Agricultural research centre	22
Politics	Ministry of the Environment, Nature, Forests, Rural Affairs and Animal Welfare	23
	Waste authorities	24
Other	Environmental and consumer protection authorities	25
	Federation of waste management and environmental companies	26
	Waste management association	27
	Regional economic development office	28

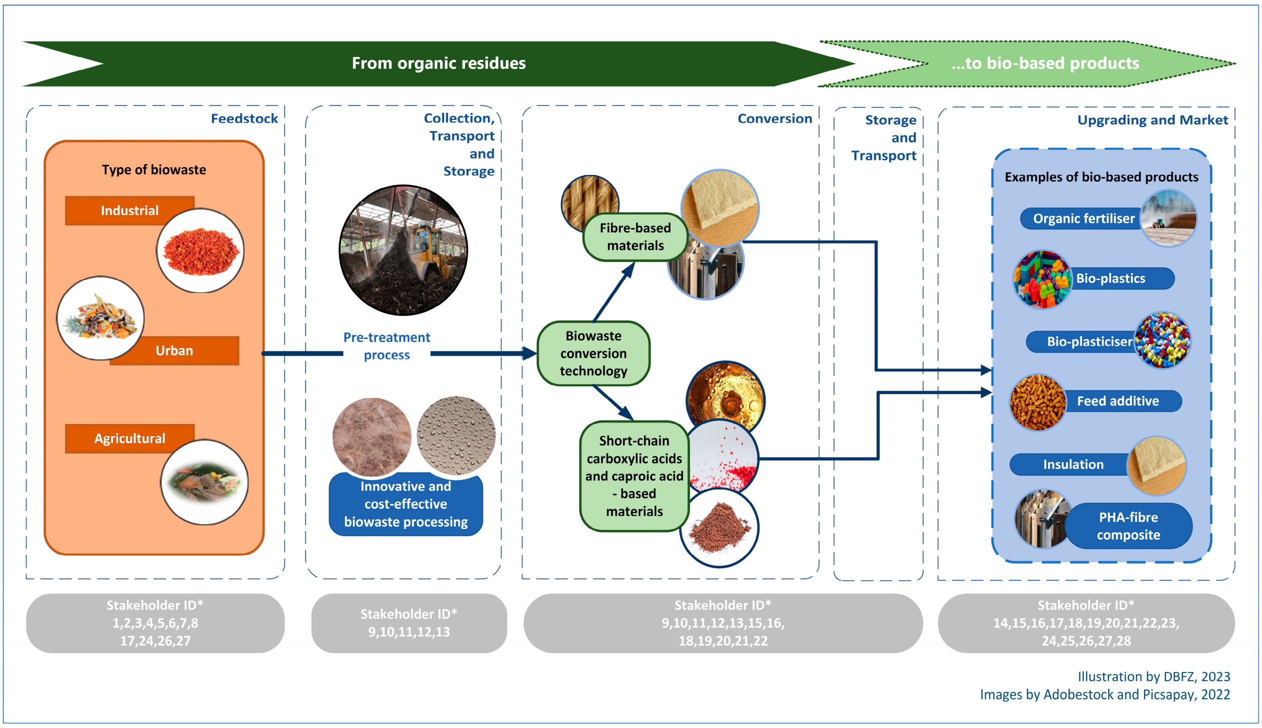

Figure 2. Scheme of a biowaste supply chain in Wallonia, Belgium and stakeholder relevance along the chain [21]. * Stakeholder IDs are shown in Table 1.

2. Materials and Methods

2.1. Analytical Approach

The analytical framework used in this study is the PESTEL analysis [24]. This method can be used to determine important hindrances and enablers to biowaste supply chains by analyzing the macro-environment in terms of political, economic, social, technical, environmental and legal aspects [24]. Specifically, the category 'infrastructure' was added to the PESTEL method to create PESTEL+I [25,26], which can be used to evaluate bioeconomy supply chains. In this study, the geographic focus was the Wallonia region in Belgium and the area surrounding the biowaste pilot plant in Tenneville, where supply chain stakeholders and infrastructure are located. The entire dataset is derived from the CAFIPLA project in Wallonia. The data were collected through desk research, during semi-structured interviews, stakeholder engagement workshops and discussion round tables in a stepwise process which is described by Blümel et al. [25]. First, stakeholder categories were defined and a list of relevant stakeholders was drawn up. A radius of 50 km around the pilot plant was defined as the limit for resource accessibility within the project. Accordingly, mainly feedstock suppliers within this radius were identified and analyzed (unpublished data).

2.2. Data Collection

Firstly, relevant stakeholder groups were categorized as upstream (e.g., municipalities, breweries, pasta producers), midstream/conversion (e.g., biogas plant, waste and recycling industry) and downstream (e.g., bio-based market customers, biochemicals industry). Later during the research process, the focus was slightly narrowed to feedstock suppliers (upstream) and conversion activities since the technology is currently not immediately ready for market and has a low technology readiness level (TRL) of 5. Nevertheless, it became obvious that policymakers, both at EU and local levels, are key to supporting or impeding biowaste valorisation supply chains.

The stakeholder network identified in the region comprised feedstock suppliers, competitors for feedstock, collection and transportation stakeholders, service providers and plant operators, which all belong to relevant parts of the supply chain (Table 1, Figure 2).

Consequently, all activities and processes performed by these stakeholders, such as the collection, pre-treatment and conversion of biowaste, were discussed at the stakeholder workshops.

Secondly, expert interviews and workshop discussions brought to the surface relevant issues and factors that stakeholders may face when involved in the supply chain. In a third step, several researchers taking part in the research project independently coded the data by using by using a "Computer Assisted Qualitative Data Analysis Software" (CAQ-DAS, NVivo 1.6.1 [27]) within the PESTEL+I scheme to ensure intercoder reliability [25]. This minimised single perspectives and biases. The preliminary PESTEL+I analysis was discussed in stakeholder workshops and round table meetings at the end of the project to collect further input on the successful implementation of the supply chain in Wallonia. Finally, hindrances and enablers relevant for the biowaste supply chain (Figure 2) are assigned to each of the PESTEL+I categories (the 1st and 2nd tables in Section 3).

3. Results

PESTEL+I

Our analysis revealed a number of hindrances (Table 2) and enablers (Table 3) along the supply chain. These factors were placed into PESTEL+I categories. The primary obstacles are found under the political, legal, technological and economic categories. The main enablers fall under the legal, economic and social categories.

1. Hindrances for the Biowaste Supply Chain

Table 2. PESTEL+I analysis of hindrances (H).

PESTEL+I Categories	Hindrances (H)
Political	- H1: EU guidelines for waste disposal and treatment have not yet been implemented uniformly across the EU. Implementing EU legislation is a long process. EU waste directives can overlap with regional administration policies. This uncertain legal situation hinders investment in new concepts and technology. - H2: In Belgium, decision-making powers are decentralised and granted to three different regions (Flanders, Wallonia and metropolitan Brussels) and waste management is regulated at the regional and municipal level. - H3: Lobbying by competing sectors such as the fossil-based industry (fossil-based plastics), bioenergy, waste ignition and palm oil industry (crop-based bio-plastics) prevent large-scale market uptake of recycled biowaste-based products.
Economical	- H4: Companies and standards demand the same properties in bio-based products and feedstocks that petroleum/fossil-based products have. - H5: Highly automated manufacturing equipment and production lines are very expensive. Investing in new technologies and retrofitting leads to high costs and effort. - H6: Limited access to available, affordable feedstock of a suitable quality and consistency could lead to higher prices for some of the bio-based products (e.g., biopolymers 2–6 USD/kg, marketsandmarkets.com) and reduces competitiveness to petroleum-based alternatives (1–2 USD/kg). - H7: Technology cannot achieve industrial-scale production; pilot plant trials require accurate calculation of process parameters for operation at a larger scale. - H8: Cost-benefits have not yet been calculated; investment costs and other expenses (OPEX, CAPEX) need to be offset against financial, social and environmental benefits. - H9: The high water content of municipal biowaste makes transportation challenging and therefore short transport distances are required. - H10: Due to the organic fraction of municipal and mixed household waste, the most difficult waste stream is considered to be a feedstock.

Table 2. *Cont.*

PESTEL+I Categories	Hindrances (H)
Social	- H11: Waste-based products are still not accepted by a large number of customers. - H12: Households have the greatest influence over improvement of organic waste sorting. This is where most mistakes are made in waste separation, which in turn leads to major technological and economic costs down the line.
Technological	- H13: Biowaste is heterogenous and the resulting product can fluctuate more in its composition and quality than can a petroleum-based product. - H14: The TRL level for biowaste conversion processes is low. The political framework and approval processes do not support large-scale investments (only short-term validity of guidelines, slow introduction of standards); members of standardisation bodies often come from fossil-based industries and associations which do not support bio-based applications and concepts. - H15: In contrast to their fossil-based predecessors, bioeconomy refineries must be adapted for heterogeneous resources and be able to cope with fluctuations in quality and quantity. The concept of refineries must therefore be re-envisioned.
Environmental	- H16: Impurities and toxic residues can have serious effects on direct use in manufacturing processes and on the quality of the manufactured materials and products. - H17: Bio-plastic products can create problems in recycling and composting processes.
Legal	- H18: (Regional) legislation for waste (end-of-waste), recycling and consumer protection needs to be updated. Current regional legislation (e.g., classifications of 'wastes' and 'by-products' in the Walloon Environmental Permit Statute 1999) and related regulations are preventing timely modifications of existing systems because the adaption process is too slow. Waste pre-treatment and sorting systems should be adapted to integrate new innovative technologies and processes. - H19: The heterogeneous and versatile nature of biowaste and biowaste-based products is not considered in common (ISO) standards which is currently focused on petroleum-based chemicals and products. - H20: Legislation on the application of biowaste products for medical and food purposes foresees high hurdles and standards to prevent contamination and subsequent health issues.
Infrastructural	- H21: Feedstock availability: high qualitative and quantitative variation and annual/temporal fluctuations in the heterogeneous feedstock is challenging. - H22: Availability of waste streams varies from region to region. - H23: Logistics, collection and sorting systems are not adapted to meet the increasing and multifaceted demands from industrial sectors and energy suppliers. - H24: Even though there is usually an infrastructure for household biowaste and mixed household waste, it must be adapted to achieve better selective collection and quality for new industrial applications. - H25: There are certain challenges in the storage of biological waste that need to be addressed to ensure the continuous operation of the facility.

2. Enablers for the Biowaste Supply Chain

While Table 2 outlines many hindrances, our analysis shows that there are enabling factors that could push for the establishment of supply chains at the regional level (Table 3). Enablers are mainly associated with legal and economic aspects.

Table 3. PESTEL+I analysis of enablers (E).

PESTEL+I Categories	Enablers (E)
Political	- E1: Amending Directive (EU) 2018/850 [28] on the landfill of waste and - Amending Directive (EU) 2018/851 on waste [29,30] support increased reuse and recycling (E2–E5). For example: • E2: By 2025, 55% of municipal waste must be prepared for reuse and recycling; this increases to 60% by 2030 and 65% by 2035 [28]. • E3: The amount of landfilled municipal waste must be reduced to ≤10% of the total amount of municipal waste generated by 2035 [28]. • E4: From 2030 onwards, all waste suitable for recycling or other forms of recovery, in particular municipal waste, may not be placed in a landfill [28]. • E5: By 2023, member states must ensure that biowaste is either separated and recycled at source or is collected separately and not mixed with other types of waste [29]. - E6: Article 6 of (EU) 2018/851[29] describes the end-of-waste status and encourages recycling, including composting and digestion of biowaste, taking into account specific environmental guidelines. - E7: The EC JRC, Institute for Prospective Technological Studies, proposed a methodology describing how to convert biowaste into a market product based on the end-of-waste criteria [31]. - E8: Future amendments of RED II and initiatives for a REMD (renewable energy and material directive) support the use of high-value bio-based materials [32]. - E9: Tax breaks or a subsidy scheme for the non-energetic use of biowaste and higher taxes for energetic use can create incentives for market growth of bio-based non-energetic use in the bioeconomy.
Economical	- E10: Financial incentives for companies in the EU emission trading system (EU ETS) and a high price for carbon dioxide (CO_2) can stimulate the market. - E11: A complete phase-out by 2030 of palm oil, currently classified as a feedstock with a high risk of indirect land use change (iLUC), supports the market uptake of alternative bio-waste feedstocks [33]. - E12: Technological innovation, knowledge creation and IP (intellectual property) benefit a region's economic development. - E13: Waste valorisation can generate value instead of costs. Because some companies have to pay to dispose of residues, costs can now be lowered and value can even be created.
Social	- E14: There is a high demand and trend for 100% bio-based products which protect the climate and environment [33]. Increasing TRL levels and lower production costs (including feedstock costs with 60–70% of total production costs) will lead to lower overall product costs and increasing market acceptance. Improved product performance allows products to compete with fossil-based counterparts [34].
Technological	- E15: Research results are promising and there is a growing number of technologies being developed in the field. This leads to competition and accelerates research & development. - E16: Specific wastes can be collected directly from the waste producers (e.g., food industry) and delivered to the conversion plant to avoid mixing and contamination with other wastes and unwanted compounds.
Environmental	- E17: Replacement of fossil materials and products with bio-based materials to reduce emissions. - E18: Biowaste streams will be upgraded in terms of their "sustainability value", e.g., residues are often used as feed additives in bioenergy applications. They can be upgraded into materials with the new technology. This will boost the development of the circular economy.

Table 3. *Cont.*

PESTEL+I Categories	Enablers (E)
Legal	- E19: The European Committee for Standardisation (CEN) is developing standards in the areas of bio-lubricants, bio-polymers, bio-surfactants and bio-solvents [35]. - E20: The Lead Market Initiative aims to support the up-take of sectors identified as having policy instruments (regulation, public procurements, standardisation and other supporting activities) [36]. - E21: Mandates M/429 (for the elaboration of a standardisation programme for bio-based products), M/430 (on bio-polymers and bio-lubricants), M/491 (on bio-solvents and bio-surfactants) and M/492 (for the development of horizontal standards for bio-based products) were issued by the EC and accepted by CEN [37]. - E22: Some of the conversion products (carboxylic acid C1–C5, carboxylic acid C5–C9, caproic acid/hexanoic acid, PHB are already registered at REACH/ECHA [38–40]. Only co-admission has to be obtained, which is less time consuming and less expensive. - E23: Since the contracts and approvals for organic, municipal bio-waste and green waste have already been negotiated at the existing pilot sites, preparation for follow-up projects is underway.
Infrastructural	- E24: Specific wastes can be collected directly from the waste producers (e.g., food industry) and delivered to the conversion plant to avoid mixing and contamination with other wastes and unwanted compounds. - E25: Think locally, create local supply chains to reduce carbon emissions and dependencies on imports (sustainability, low carbon footprint).

4. Discussion

While our PESTEL+I analysis shows that there are both hindering and enabling factors (Figure 3), the ambiguity of the legislative framework and the overlap of regulations at the EU and regional levels are hard to overcome and can negatively affect each step in the biowaste supply chain. The EU legal framework for end-of-waste applications is rather general and not well-defined for some of the new waste fractions [28,29,41]. Furthermore, there is a confusing asymmetry in EU regulations and in much of the regulatory framework at the regional level, especially in complex political systems like in Belgium, where regional authorities are responsible for enforcing EU legislation [42]. This can hamper processes as they may be more outdated than EU standards or current innovative methods for waste pre-treatment, collection and sorting. As a result, the fuzzy legal framework influences each step of the supply chain—from the unclear standards and criteria for waste collection and pre-treatment, to the high criteria for food or medical bio-based products. Nevertheless, the EU legal framework supports the competitiveness of biowaste supply chains in certain aspects. Amending Directive (EU) 2018/850 [28] on the landfill of waste and Amending Directive (EU) 2018/851 on waste [29] introduce higher quotas for reuse and recycling of municipal waste and massively lowers the amount of biowaste permitted for landfills. For example, 65% of municipal waste must be prepared for reuse and recycling by 2035, and biowaste must be either separated and recycled at source or collected separately and not mixed with other types of waste. Moreover, the EU Land Use and Land Use Change Forestry (LULUCF) guidelines [33] have developed sustainability criteria for land use. This means certain feedstocks with a high risk of indirect land use change (iLUC) will not be supported or will be phased out for further processing, e.g., in biorefineries. The industry will therefore try to replace unsustainable feedstocks which could be partly derived from regionally available biowaste [20].

In the upstream part of the supply chain, one hindrance is associated with the heterogeneity of biowaste [43]. The high presence of toxic residues and impurities in biowaste not only makes it difficult to sort and treat but also requires innovative and finely tuned technologies which currently do not exist. Adding to this, the regional legislation in Wallonia does not support the technological upgrades required. Another hindrance is the long distance (>50 km) that biowaste has to be transported, in some cases, for collection, storage and treatment. Therefore, only smaller amounts of biowaste can be collected. In turn, this places into question the development of the economies of scale needed for cost-effective and resource-efficient downstream processing of bio-based products. Thus, the economy of scale still has to develop in the next years and cost-benefit calculations must be conducted. Moreover, life cycle assessment (LCA), life cycle costing (LCC) and social life cycle assessment (S-LCA) of the upscaled CAFIPLA concept will have to be completed to enable market uptake of the derived products and business models [8,44]. Finally, there is a lack of intersectoral cooperation and regional incentives for waste management. The high costs of biogas plant conversions, collection and pre-treatment of the feedstock and evolution of the manufacturing processes of downstream customers can hinder a rapid integration of the biowaste supply chain concept and its products into the market. Many stakeholders pointed out the need to deepen business-to-business (B2B) relations (e.g., relations between the food industry/food stores, waste handlers and municipal utilities) and to push for cross-sectoral partnerships/collaborations. Connections across different industrial sectors (waste, recycling, chemical industry) must be reinvented [20].

Regarding the downstream part of the supply chain, hurdles obstructing the use of biowaste products in the food and pharmaceutical sectors must be lowered and standard procedures have to be adapted for the specific requirements of heterogeneous and varying bio-based materials and products. These should differ from the requirements for petroleum/fossil-based products. The industry and policymakers have not yet changed their mindset to fully support a circular sustainable economy [45,46]. In addition, the unstable, frequently changing legal and market situation is unable to provide investment security and will deter many companies from adopting biowaste valorisation concepts. Long-term uptake agreements could be delayed or postponed. However, there is an increasing number of interested clients as well as a higher social acceptance of the use of biowaste products and a stigmatisation of fossil-based products. Additionally, massive financial incentives for companies resulting from the ETS and high CO_2 price, as well as a high demand from industry will support further uptake and upscaling of the supply chain concepts. Enormous environmental and economic savings from the recovery of food waste resources have been estimated in other research studies [47].

Our findings are not surprising in the field of circular economy and waste management. For example, Malinauskaite and colleagues (2017) point to the missing harmonisation of guidelines on municipal solid waste which hinders a fully encompassed valorisation of waste for EU circular economy: "It seems that the European Commission is set to provide further clarity on the notion of MSW to avoid any ambiguities among the Member States" [48]. Another relevant study argues that there are conflicting objectives for the classification of wastes and chemicals as well as for the distinction between waste and further processed products. Interfaces between waste and chemical regulation and product law have to be clarified to implement a circular economy [49]. Salmenperä (2021) describes critical factors to enhance the circular economy while emphasizing the illustration of economic benefits, improved sharing of waste-related data and increased dialog between key players [50].

Based on our results, we have summarised the following recommendations to boost biowaste valorisation in Wallonia, which may be also be applicable to other European regions:

- Establish a regional regulatory framework to allow the creation of a market for biowaste products.
- Create a new category in waste legislation in Belgium for biowaste-based products.
- Form a task force at the regulatory authority (Wallonia: "Service Public de Wallonie (SPW)") which should focus on biowaste-based products and the development of related legal criteria and detailed standards for end-of-waste processes.
- Form intersectoral associations of stakeholders and investors (food producers/feedstock, chemical industry/customers).

- Involve investors regardless of currently low TRL of the conversion technology and initiate joint follow-up upscaling feasibility projects.
- Create patents and green labels which will increase the credibility of the technology and products.
- Market the concept as a product portfolio, not only as single products.
- Invest in further R&D and upscaling and raise the TRL of the biowaste conversion technologies.
- Decrease production costs (with feedstock costs making up 60–70% of total production costs).
- Improve product performance to achieve competitiveness with fossil-based counterparts.
- Support and advocate for long-term validity of guidelines and accelerate introduction of standardisation guidelines at the local level.
- Explore further incentives in the EU emission trading system (EU ETS). Utilise the high carbon dioxide (CO_2) price to stimulate market uptake.
- Adapt logistics, collection, storage and sorting systems to multiple demands of different industrial sectors.
- Use new artificial intelligence and digitalisation tools to create platforms that allow estimation of regionally available biowaste potentials and optimise logistics.

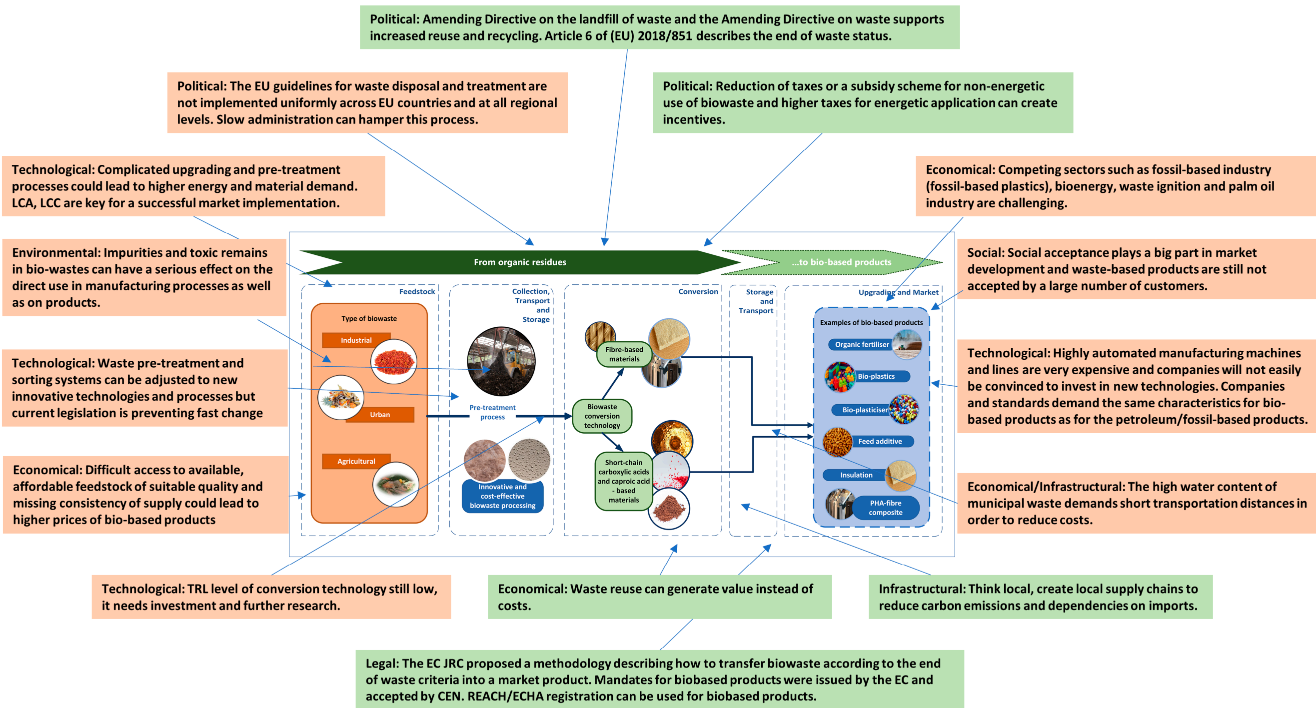

Figure 3. A summary of selected PESTEL+I factors (hindrances (red) and enablers (green)) along a biowaste supply chain in Wallonia, Belgium (see also Tables 2 and 3).

5. Conclusions

Our analysis of hindrances (Table 2) and enablers (Table 3) shows that many challenges still have to be overcome, especially at the political and regulatory level, since EU guidelines and their amendments determine further development and market uptake support for circular economy concepts [28–30]. The following conclusions were drawn from our findings:

- Complex and unclear guidelines in different regions (e.g., in Belgium: Wallonia, Flanders, metropolitan Brussels) and EU member states hinder the implementation of the CAFIPLA concept in real markets and may deter interested companies.
- Nevertheless, recent and upcoming EU guidelines and amendments [31–33], planned harmonisation of waste policies in Belgium by 2025 and preparation of standardisation

guidelines and mandates for bio-based products [35–37] may support the valorisation and recycling of biowaste.

- The industry is demanding that alternative resources and materials become more independent of external sources and fossil-based input. Joint activities between all associated stakeholders (municipalities, regional waste disposal, recycling and other companies) are required to take advantage of the situation and encourage policymakers and industry networks to create new circular concepts similar to CAFIPLA [17,21].
- The PESTEL+I analysis highlighted the most important factors which hinder or support a market shift, and recommendations were developed based on this. The most crucial step would be to create a new category in waste legislation in Wallonia as well as other Belgian regions for bio-based products.
- A related task force, coordinated by the regulatory authorities (e.g., SPW) [22,23], should focus on bio-based products, legal criteria and detailed end-of-waste standards to pave the way for a large-scale market uptake in a future circular bioeconomy in Belgium and in Europe.

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References

1. European Commission. European Green Deal: Delivering on Our Targets. Available online: https://ec.europa.eu/commission/presscorner/api/files/attachment/869807/EGD_brochure_EN.pdf.pdf (accessed on 19 June 2023).
2. European Commission. A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment: Updated Bioeconomy Strategy. 2018. Available online: https://data.europa.eu/doi/10.2777/792130 (accessed on 20 May 2023).
3. Andersson, J.O.; Lindroth, M. Ecologically unsustainable trade. *Ecol. Econ.* **2001**, *37*, 113–122. [CrossRef]
4. Burritt, R.L.; Schaltegger, S. Measuring the (un-)sustainability of industrial biomass production and use. *Sustain. Account. Manag. Policy J.* **2012**, *3*, 109–133. [CrossRef]
5. European Environment Agency. Bio-Waste in Europe: Turning Challenges into Opportunities. Available online: https://www.eea.europa.eu/publications/bio-waste-in-europe/download (accessed on 20 May 2023).
6. European Commission. Guidance on Cascading Use of Biomass with Selected Good Practice Examples on Woody Biomass. Available online: https://data.europa.eu/doi/10.2873/68553 (accessed on 20 May 2023).
7. World Economic Forum WEF. *Project MainStream Urban Biocycles: System Initiative on Environment and Natural Resource Security*. 2017. Available online: https://www3.weforum.org/docs/WEF_Project_MainStream_Urban_Biocycles_2017.pdf (accessed on 17 April 2023).
8. Nordahl, S.L.; Devkota, J.P.; Amirebrahimi, J.; Smith, S.J.; Breunig, H.M.; Preble, C.V.; Satchwell, A.J.; Jin, L.; Brown, N.J.; Kirchstetter, T.W.; et al. Life-Cycle Greenhouse Gas Emissions and Human Health Trade-Offs of Organic Waste Management Strategies. *Environ. Sci. Technol.* **2020**, *54*, 9200–9209. [CrossRef] [PubMed]

9. European Commission. EU Bioeconomy Strategy Progress Report: European Bioeconomy Policy: Stocktaking and Future Developments. Available online: https://op.europa.eu/o/opportal-service/download-handler?identifier=ae0a36d3-eac3-11ec-a534-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part= (accessed on 20 May 2023).
10. Chia, W.Y.; Chew, K.W.; Le, C.F.; Lam, S.S.; Chee, C.S.C.; Ooi, M.S.L.; Show, P.L. Sustainable utilization of biowaste compost for renewable energy and soil amendments. *Environ. Pollut.* **2020**, *267*, 115662. [CrossRef] [PubMed]
11. Sakir, S.; Raman, S.N.; Safiuddin, M.; Amrul Kaish, A.B.M.; Mutalib, A.A. Utilization of by-products and wastes as supplementary cementitious materials in structural mortar for sustainable construction. *Sustainability* **2020**, *12*, 3888. [CrossRef]
12. MUSIC. Deliverable D5.5—Set of Four Strategic Case Studies (Public Edition). Available online: https://www.music-h2020.eu/publications-reports/ (accessed on 20 July 2023).
13. Jain, A.; Sarsaiya, S.; Kumar Awasthi, M.; Singh, R.; Rajput, R.; Mishra, U.C.; Chen, J.; Shi, J. Bioenergy and bio-products from bio-waste and its associated modern circular economy: Current research trends, challenges, and future outlooks. *Fuel* **2022**, *307*, 121859. [CrossRef]
14. Joint Research Centre JRC. *ENSPRESO—BIOMASS: Dataset*. 2019. Available online: http://data.europa.eu/89h/74ed5a04-7d74-4807-9eab-b94774309d9f (accessed on 21 July 2022).
15. Günther, S.; Karras, T.; Semella, S. Theoretical biomass potentials for EU 27. *OpenAgrar* **2023**. [CrossRef]
16. European Commission. Annual Production Series of Dairy Products: Milk Collection and Dairy Products Obtained, Production and Utilization of Milk on the Farm. Available online: https://agriculture.ec.europa.eu/system/files/2023-03/eu-dairy-historical-production-stocks-series_en.pdf (accessed on 24 April 2022).
17. CAFIPLA. Deliverable D1.5—Final Report on the Market Assessment of CAP/FRP Based Bioproducts and CAFIPLA as Technology in the Bio-Economy Expansion. Available online: https://cafipla.eu/wp-content/uploads/2023/02/D1.5_Final-Market-Assessment.pdf (accessed on 20 June 2023).
18. European Commission. A New Circular Economy Action Plan: For a Cleaner and More Competitive Europe. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed on 27 April 2023).
19. Baldoni, E.; Philippidis, G.; Spekreijse, J.; Gurría, P.; Lammens, T.; Parisi, C.; Ronzon, T.; Vis, M.; M'Barek, R. Getting your hands dirty: A data digging exercise to unearth the EU's bio-based chemical sector. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110895. [CrossRef]
20. Mahjoub, B.; Domscheit, E. Chances and challenges of an organic waste–based bioeconomy. *Curr. Opin. Green Sustain. Chem.* **2020**, *25*, 100388. [CrossRef]
21. CAFIPLA Project Consortia. CAFIPLA Website: Objectives. Available online: https://cafipla.eu/home_cafipla/about/ (accessed on 7 November 2022).
22. Service Public de Wallonie. Walloon Waste-Resources Plan. *Non-Technical Summary of the Draft Plan*. Available online: https://sol.environnement.wallonie.be/files/PWDR/WWRP-NTS-EN.pdf (accessed on 3 May 2023).
23. Service Public de Wallonie. Génération de Déchets Ménagers et Assimilés. Available online: http://etat.environnement.wallonie.be/contents/indicatorsheets/MEN_9.eewGeneratePdf.do (accessed on 3 May 2023).
24. Achinas, S.; Horjus, J.; Achinas, V.; Euverink, G.J.W. A PESTLE Analysis of Biofuels Energy Industry in Europe. *Sustainability* **2019**, *11*, 5981. [CrossRef]
25. Blümel, L.; Siegfried, K.; Riedel, F.; Thrän, D. Are strategy developers well equipped when designing sustainable supply chains for a circular bio-economy?: Supporting innovations' market uptake in a PESTEL+I environment. *Energy Sustain. Soc.* **2023**. *accepted*.
26. Siegfried, K.; Blümel, L.; Riedel, F.; Moosmann, D.; Cyffka, K.-F.; Richters, M.; Reumerman, P.; Vos, J.; Matisons, M.; Thrän, D. Plating the Hot Potato—How to Make Intermediate Bioenergy Carriers an Accelerator to a Climate Neutral Europe. 2023. Under Rev. Available online: https://www.researchsquare.com/article/rs-2025787/v1 (accessed on 1 January 2022).
27. QSR International Pty Ltd. 2018. NVivo 1.6.1. Available online: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home (accessed on 1 January 2022).
28. Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste. *Off. J. Eur. Union* **2018**, *150*, 100–130.
29. European Union (EU). *Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on Waste*; OJ L150/109; European Union: Brussels, Belgium, 2018; Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0851&rid=5 (accessed on 1 January 2022).
30. Municipal Waste Europe. Summary of the Current EU Waste Legislation. Available online: https://www.municipalwasteeurope.eu/summary-current-eu-waste-legislation (accessed on 7 November 2022).
31. Catarino, A.S.; Alejandro, V.; Litten, D.; Eder, P.; Luo, Z.; Delgado, L. End-of-Waste Criteria: Final Report. Available online: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC53238/jrc53238.pdf (accessed on 20 June 2023).
32. European Commission. EU Policy Framework on Biobased, Biodegradable and Compostable Plastics. Available online: https://environment.ec.europa.eu/topics/plastics/biobased-biodegradable-and-compostable-plastics_en (accessed on 4 November 2022).
33. Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the Inclusion of Greenhouse Gas Emissions and Removals from Land Use, Land Use Change and Forestry in the 2030 Climate and Energy Framework, and Amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018R0841 (accessed on 1 January 2022).

34. Ghi, T.; Webster, P.; Monzon, D.; Cheng, W.; Srisaard, P.; Lim, S.; Kolk, M.; Cheng, W.; Lim, P.S.S. Why the Biobased Materials Market Is Finally Poised for Growth. Available online: https://www.adlittle.com/en/insights/prism/why-bio-based-materials-market-finally-poised-growth (accessed on 4 November 2022).
35. BioBasedEconomy. CEN/TC 411 Bio-Based Products. Available online: https://www.biobasedeconomy.eu/centc-411-bio-based-products/ (accessed on 7 November 2022).
36. European Commission. A Lead Market Initiative for Europe: COM (2007) 860 Final. Available online: https://www.eea.europa.eu/policy-documents/a-lead-market-initiative-for-europe (accessed on 4 November 2022).
37. BioBasedEconomy. Standardization in the Bio-Based Economy. Available online: https://www.biobasedeconomy.eu/standardization-2/ (accessed on 7 November 2022).
38. European Chemicals Agency ECHA. Carboxylic Acids, C5-9. Available online: https://echa.europa.eu/en/substance-information/-/substanceinfo/100.065.141 (accessed on 7 November 2022).
39. European Chemicals Agency ECHA. Biopol. Available online: https://echa.europa.eu/en/substance-information/-/substanceinfo/100.125.321 (accessed on 7 November 2022).
40. European Chemicals Agency ECHA. Hexanoic Acid. Available online: https://echa.europa.eu/de/substance-information/-/substanceinfo/100.005.046 (accessed on 7 November 2022).
41. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32008L0098 (accessed on 1 January 2022).
42. van Thuyne, G.; Gossens, F.; Environmental law and practice in Belgium: Overview. Global Guide 2015. Available online: https://content.next.westlaw.com/practical-law/document/I203078f01cb611e38578f7ccc38dcbee/Environmental-Law-and-Practice-in-Belgium-Overview?viewType=FullText&transitionType=Default&contextData=(sc.Default) (accessed on 1 January 2022).
43. Yamakawa, C.K.; Qin, F.; Mussatto, S.I. Advances and opportunities in biomass conversion technologies and biorefineries for the development of a bio-based economy. *Biomass Bioenergy* **2018**, *119*, 54–60. [CrossRef]
44. Giuntoli, J.; Bulgheroni, C.; Marelli, L.; Sala, S.; Pant, R.; Lusser, M.; Avraamides, M. *Brief on the Use of Life Cycle Assessment (LCA) to Evaluate Environmental Impacts of the Bioeconomy*; European Commission: Brussels, Belgium, 2019. [CrossRef]
45. Kivimaa, P.; Boon, W.; Hyysalo, S.; Klerkx, L. Towards a typology of intermediaries in sustainability transitions: A systematic review and a research agenda. *Resour. Policy* **2019**, *48*, 1062–1075. [CrossRef]
46. Kuckertz, E.S.C.; Berger, C.A.; Reyes, M. Entrepreneurial ventures and the bioeconomy. In *Bioeconomy—Shaping the Transition to a Sustainable, Biobased Economy*; Lewandowski, I., Ed.; Springer: Berlin/Heidelberg, Germany, 2018; pp. 273–284, Chapter 8.
47. Slorach, P.C.; Jeswani, H.K.; Cuéllar-Franca, R.; Azapagic, A. Environmental and economic implications of recovering resources from food waste in a circular economy. *Sci. Total Environ.* **2019**, *693*, 133516. [CrossRef] [PubMed]
48. Malinauskaite, J.; Jouhara, H.; Czajczyńska, D.; Stanchev, P.; Katsou, E.; Rostkowski, P.; Thorne, R.J.; Colón, J.; Ponsá, S.; Al-Mansour, F.; et al. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy* **2017**, *141*, 2013–2044. [CrossRef]
49. Friege, H.; Kummer, B.; Steinhäuser, K.G.; Wuttke, J.; Zeschmar-Lahl, B. How should we deal with the interfaces between chemicals, product and waste legislation? *Environ. Sci. Eur.* **2019**, *31*, 51. [CrossRef]
50. Salmenperä, H.; Pitkänen, K.; Kautto, P.; Saikku, L. Critical factors for enhancing the circular economy in waste management. *J. Clean. Prod.* **2021**, *280 Pt 1*, 124339. [CrossRef]