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# Food, energy or biomaterials? Policy coherence across agro-food and bioeconomy policy domains in the EU

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ABSTRACT

The European Union (EU) envisions a shift towards a bioeconomy to address challenges such as reducing dependence on non-renewable resources, managing natural resources sustainably and food security. As a result, biomass will become an increasingly important resource in the bioeconomy. This will require careful and sustainable management especially because biomass comes from a wide variety of economic sectors and is governed by different policies. The bioeconomy will, therefore, require coherence between many different policy domains. However, little is known how policy goals in these domains interact and how these interactions may play out in different contexts. Hence, this study aims to assess coherence between bioeconomy and agro-food policies by assessing the interactions between bioeconomy and agro-food goals (i.e. trade-offs, synergies) as well as revealing knowledge gaps. Utilising qualitative content analysis, a survey and focus groups, we find that bioeconomy policy goals and agro-food policy goals are largely considered to be consistent, when considering coherence scores only, and that synergies outweigh trade-offs, both in quantity and in strength. However, all bioeconomy policy domains show some trade-offs with agro-food policy. We furthermore find disagreement (i.e. range of scores) and uncertainty in scientific knowledge-base, particularly concerning waste and bio-based industry. Disagreement surrounds the feasibility of some policy goals, such as decoupling economic growth from the environment. We conclude that a shift towards a bioeconomy will have to acknowledge the interactions between different policy goals across the different sectors and avoid 'silo-thinking'. This can be achieved through addressing vagueness in policies and allowing integrated policies to embrace uncertainty.

## 1. Introduction

Humans use biomass for multiple purposes, such as the production of food, livestock feed, bioenergy and bio-based materials (e.g. bio-plastics, cellulose fibres, pharmaceuticals). Due to the growth of the global population and changing patterns of consumption, humans are appropriating more biomass than ever before (Krausmann et al., 2013; Smil, 2012). Food demand is expected to increase by 50 % between 2012 and 2050 (FAO, 2017) and the increasing demand for animal-source food will entail higher animal feed demands and will increase pressure on agricultural resources (Thornton, 2010). Bioenergy, already an important source of renewable energy, representing 64 % of all renewable energy in the EU (Eurostat, 2016) is also expected to increase as the EU seeks to meet 20 % of its gross energy consumption through renewables. As economies shift to become more bio-based, demands will also increase for bio-based products such as bioplastics, biolubricants and biochemicals (Scarlat et al., 2015). If these trends remain unchanged, it will become increasingly difficult to meet growing demands without increasing pressure on water, land and other natural resources (Muscat et al., 2019). Competing uses for biomass pose a challenge of how to meet biomass demand while also managing natural resources sustainably (Godfray et al., 2010). Several studies have so far assessed the potential biomass available now and in the future to meet human demands (Daioglou et al., 2019; Scarlat et al., 2011; Verkerk et al., 2019). However, these studies often focus on only one or two biomass uses (for food, feed, fuel, materials etc.) without considering systems-level connections between food-systems, energy-systems and other bio-based systems (e.g. forestry). This results in science recommending either piecemeal or inconsistent solutions that lead to several trade-offs (Muscat et al., 2019).

There is growing interest in both science and policy to define and move towards a bioeconomy. Despite this, the concept remains hotly

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contested and is approached from a wide-number of perspectives, disciplines and policy aims (Befort, 2020; Vivien et al., 2019). In 2012, the European Union (EU) adopted the bioeconomy strategy to meet the challenges of mitigating climate change, moving away from non-renewable resources, managing resources sustainably and achieving food and nutrition security. In this study, we utilise the EU's definition of the bioeconomy as '*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'* (European Commission, 2012). The bioeconomy encompasses all economic sectors where biomass is extracted and recovered, linking primary sectors, such as the agricultural, aquaculture and forestry sector, with industrial and processing sectors, such as the chemical, energy and biotechnology sectors (Kelleher et al., 2019). Biomass streams within the bioeconomy can range from food, feed and energy crops, to forestry felling, municipal solid waste and industrial residues. However, the diversity of biomass streams and the economic sectors where biomass is sourced poses a challenge for the governance of the bioeconomy (Kelleher et al., 2019). This is because it requires cooperation between several policy domains and a collective effort to mitigate the impact of trade-offs across different policy goals (Ronzon and Sanjuán, 2020). This will not just mean balancing demands for biomass for different uses but also implies balancing other goals; both within the bioeconomy (e.g. sustainable resource use) but also outside (e.g. maintaining and regenerating biodiversity)(European Environmental Agency (EEA), 2018). Given the above challenges, it will be difficult to maintain policy coherence between bioeconomy policy and other policy domains.

In light of the adoption of the Sustainable Development Goals (SDGs) and the need to overcome policy 'silos' (i.e. sectoral policies), policy coherence itself has become an important governance goal for the EU (Nilsson et al., 2012). The Bioeconomy Strategy (European Commission, 2012) aims to facilitate coherence and synergies and attempts to address trade-offs emerging from the competing uses of biomass. Policy coherence has been defined as going beyond 'do no harm strategies' to fostering synergies across policy domains; identifying trade-offs across spatial scales and over time (OECD, 2016). The complexity involved in balancing goals has spurred research interest into policy coherence by looking at the interactions between policy goals and how likely they are to reinforce (create synergies) or cancel each other (create trade-offs) (International Council for Science, 2017). The call to move away from 'silo thinking' to a more integrative, systems or 'nexus' way of thinking to solve policy coherence issues has echoed across a multitude of disciplines and fields (Weitz et al., 2017). The prominent role of the agro-food system in the production, provision and utilisation of biomass means that the bioeconomy presents a unique opportunity to move towards a sustainable agro-food system. This can be achieved by fostering new technologies, circular use of resources and moving away from fossil fuels. However, it may also create conflicts between sustainability goals and may place additional demands on natural resources (OECD and Diakosavvas, 2018). Studying the potential interactions between the bioeconomy and agro-food goals can find pathways to reduce conflicts and foster synergies. Given the bioeconomy is a relatively new concept, little is known how these interactions may play out, therefore finding knowledge gaps, highlighting uncertainties and disagreement is also key.

The contrasting solutions recommended by science (Muscat et al., 2019) as well as the lack of integration between policy domains and governance bodies represents both a gap in the research and a challenge for governance and policy. It is, therefore, imperative that the complexity of interactions between policy domains is well understood. Previous policy coherence studies have addressed policy domains such as energy, climate change and forestry (Antwi-agyei et al., 2017; Harahap et al., 2017; Kalaba et al., 2014; Lindstad et al., 2015). To our knowledge, policy coherence studies have not yet addressed concepts such as the bioeconomy, particularly concerning its potential effect on agricultural and food goals. Furthermore, many do not consider key uncertainties in the knowledge-base by including measures of agreement and confidence between experts. Our aim for this study is to assess the coherence between bioeconomy and agro-food policies in the EU. We do this by assessing the coherence between bioeconomy and agro-food goals, looking into whether these goals are likely to produce trade-offs or synergies. Furthermore we show where key uncertainties and knowledge gaps lie regarding these interactions. We do this by measuring range of coherence scores and confidence levels and using focus groups to highlight uncertainties and other key aspects.

## 2. Material and methods

### 2.1. Policy coherence: definition

Policy coherence has been defined in multiple ways. It has been defined as reinforcing policy goals across government ministries, departments and agencies (OECD, 2004) and also across policy areas or domains (Gauttier, 2004). It has also been defined as *'an attribute of policy that systematically reduces conflicts and promotes synergies between and within different policy areas to achieve the outcomes associated with jointly agreed policy objectives'* (Nilsson et al., 2012: 396). In this study, we follow the definition of Nilsson et al. (2012) and define coherence as the promotion of synergies across policy areas or domains, rather than across institutional bodies such as government departments. Policy synergies are when the achievement of one policy goal aids the achievement of another (e.g. reducing meat intake for both climate policy goals and human health goals). Assessing the interactions, and their induced impacts and effects between various policy areas is possible across domains and spatial/administrative scales (Lenschow et al., 2018). In this study, we focus on horizontal and external coherence, which is the examination of coherence across one administrative scale (EU) but across different policy domains (bioeconomy vs agro-food). Furthermore, while many definitions have been provided for a policy domain, for our study we define it as a substantive topic such as environment or climate change under which policy goal-setting takes place, irrespective of the governmental institution. Studies focusing on policy coherence argue that incoherence can emerge from the tendency to make use of specialist policy knowledge within policy domains with little integration of knowledge from other domains (Tosun and Leininger, 2017). We define policy incoherence for the bioeconomy as not just emerging from a lack of integration but the complexity involved in balancing competing biomass uses with biophysical and ecological limits (Muscat et al., 2019).

### 2.2. Selection of documents and policy goals

The first stage of our analysis involved qualitative content analysis of policy documents. To find relevant documents, we utilised documents referenced in three key documents defining the bioeconomy: the 2012 Bioeconomy Strategy and the 2018 update to the Bioeconomy Strategy (European Comission, 2018) and the European Environmental Agency (EEA) report "The circular economy and the bioeconomy: Partners in sustainability"(European Environmental Agency (EEA), 2018). We further conducted searches in EURLEX, using keywords such as "food", "feed", "fuel", "bioenergy", "biofuel", "land", "fisheries", "waste", "forest", "biomass", "bioeconomy", "bio-based", "agriculture". We included several types of policy documents, such as regulations, directives and communications, but excluded non-strategic or goal-setting documents. Our selection included 41 documents related to 5 policy domains: waste, bio-based industry, environment, renewable energy and agro-food (Supplementary Material). These policy domains were chosen based on their importance to the bioeconomy, particularly as they govern economic sectors that provide biomass, utilise biomass or contain important goals for the bioeconomy (European Environmental Agency (EEA), 2018).

From these 41 documents, multiple goals could be identified for each policy domain, as presented in Supplementary Table 1. To make the final selection of goals, we conducted qualitative content analysis (Flick, 2014), using the qualitative data analysis software Atlas.ti version 8.4.4 (Friese, 2012). EU policy documents were coded for goals as stated in the document. Goals were selected based on their relevance to the research questions, particularly policy goals needed to be related to biomass production, utilisation or consumption. Selected goals stated the objective or target clearly and were delineated as such to be the purpose of the policy within the document. Goals mentioned more than once in the same or different documents were excluded. This process resulted in an overview of EU policy goals domains from 15 policy documents (Supplementary Table 1) and was used to assess the coherence.

### 2.3. Assessing coherence

To assess the coherence between bioeconomy policies and agro-food policies we used expert opinion through an online survey followed by a round of focus-groups for each policy domain.

We first presented the selected policy goals (Table 1) in an online survey to obtain expert opinion on interactions (synergies, neutral or trade-offs) between bioeconomy vs agro-food goals. Experts were chosen based on snowballing referrals. All experts were from an academic background and belonged to different scientific disciplines, aligned with the policy domains. The online survey was sent to a total of 40 experts. Experts were presented with the goals in Table 1. Experts were asked to score the effect of one policy domain of their expertise (waste, bio-based industry, environment, renewable energy) on agro-food policy goals. We received a total number of 24 responses (n = 4 for waste, n = 5 for bio-based industry, n = 10 for environment, n = 5 for renewable energy). The online survey aimed to score a large number of policy interactions and consider each interaction thoroughly. A total of 108 possible policy interactions were scored by every respondent in the online survey.

To assess the level of coherence between policy domains we employed the scoring framework used by Nilsson and colleagues, (see e. g. International Council for Science, 2017; Nilsson et al., 2018, 2012) (See Fig. 1 below).

The coherence scoring system is a 7 point scale where interactions between policy goals can be scored as positive (+ 3 to +1), meaning that the goals can positively contribute to one another, negative (-1 to -3) meaning the goals negatively affect each other, and neutral (0), where two goals are independent of each other and no interaction is known. Inspired by the 'NUSAP' approach, a system for the communication of uncertainty in science, (Van Der Sluijs et al., 2005), experts were also asked to indicate the confidence level (i.e. low, medium or high confidence) in the assessment of each goal interaction. Further, additional space for qualitative comments was provided.

After the survey, responses were gathered, the data was summarised with the median and range of the coherence score and the median of the confidence score (1 equal to 'low confidence and 3 equal to 'high confidence'). These results were then presented to experts in a focus group. A separate focus group was held per policy domain with 3–4 experts attending per focus group along with a facilitator and note-taker. The focus groups lasted for 1 to 1,5 h, were audio-recorded and notes were taken. We presented the interactions from the survey where experts agreed or disagreed the most (highest range), as the interactions where experts agree or disagree the most are likely to be the most insightful. The data was then analysed using thematic content analysis. The interactions between policy domains and agro-food policy, the result of the survey and outcomes of the expert workshops are presented in Figs. 2 and 3 and Table 2 below.

## 3. Interactions between bioeconomy and agro-food goals

This section first presents the results of the online survey (Figs. 2 and 3), before presenting the results from the focus groups. Fig. 2 shows the results from the survey considering the median score for coherence only.

**Table 1**
Selected policy goals for presentation to experts across 5 policy domains. All domains were scored against EU Agro-food policy goals.

| Policy Domain | Code | Goal | Explanation |
|---|---|---|---|
| EU Waste policy domain | | | |
| | Waste1 | Reduce waste | Adhere to the waste hierarchy and reduce waste generation |
| | Waste2 | Cascade biomass | Encourage the cascading principle taking into account all biomass-using sectors utilising biomass in the most resource-efficient way |
| | Waste3 | Energy from non-recyclables | Recover energy only from non-recyclable materials |
| | Waste4 | Ban biodegradable landfilling | Ban landfilling of biodegradable waste by 2025 |
| EU Bio-Based Industry policy domain | | | |
| | BIO1 | Sustainably scale biomass | Develop sustainable scaling up of biomass supplies |
| | BIO2 | New bio-based products | Develop new bio-based products and materials |
| | BIO3 | Utilise unused residues | Encourage innovation to exploit currently unused crop residues and marine biomass |
| | BIO4 | Replace fossil-with bio-based products | Replace fossil-based products with bio-based, recyclable and marine-degradable products |
| | BIO5 | Develop biorefineries | Facilitate the development of new sustainable biorefineries |
| | BIO6 | Healthy and sustainable diets | Changes in consumption promoting healthier and more sustainable diets |
| EU Renewable Energy policy domain | | | |
| | Energy1 | 32 % renewable energy | Achieve 32 % of overall gross energy consumption by 2030 from renewable energy |
| | Energy2 | 14 % renewable energy in transport | Achieve 14 % of transport (road and rail) from renewable energy |
| | Energy3 | More advanced biofuels | Incentivise biofuels made from advanced feedstocks through double-counting their energy content |
| | Energy4 | Halt indirect-land use change | Halt 'high indirect land-use change' biofuels by 2030 |
| | Energy5 | Biofuels on marginal land | Encourage biofuels grown on abandoned, severely degraded and contaminated land |
| EU Environment policy domain | | | |
| | ENV1 | Decoupling | Decouple environmental impacts from a growing economy |
| | ENV2 | No net land take | No net land take by 2050 |
| | ENV3 | Water quality | By 2020 achieve good status (quality, quantity and use) of waters in all EU river basins |
| EU Agro-food policy domain | | | |
| | Agro1 | Food security | Food security: access to safe, sufficient, nutritious food at all times |
| | Agro2 | Healthy soils | Preventing soil degradation, restoring soil at least with consistent with the current or intended use |
| | Agro3 | Domestic and organic fertiliser | Incentivise organic fertiliser production from domestic sources |
| | Agro4 | Domestic protein crops | Increase domestic protein crop production especially for livestock feed |
| | Agro5 | Reduce food waste | Reduce food losses and waste |
| | Agro6 | Resource efficiency | Resource efficiency and nutrient cycling |

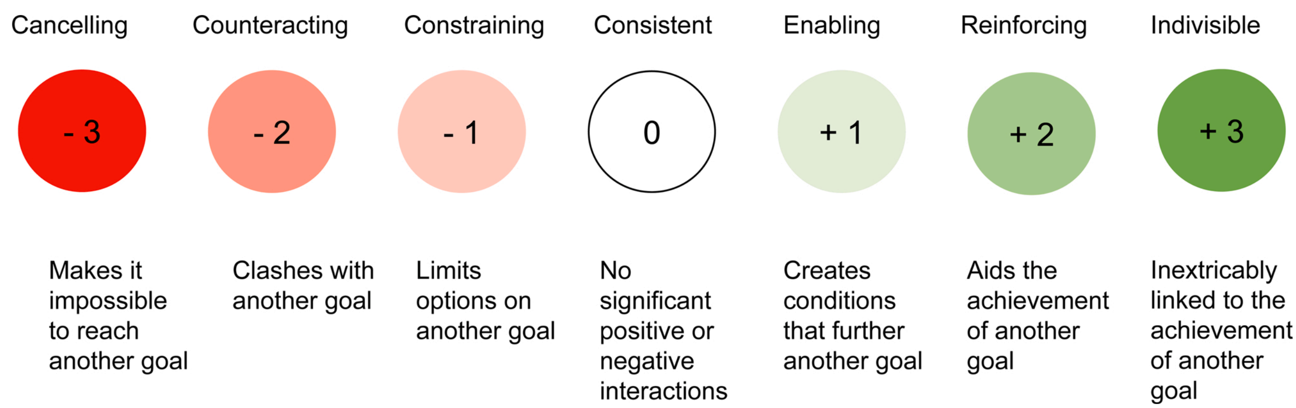


**Fig. 1.** Coherence scoring system (adapted from Nilsson, 2017).

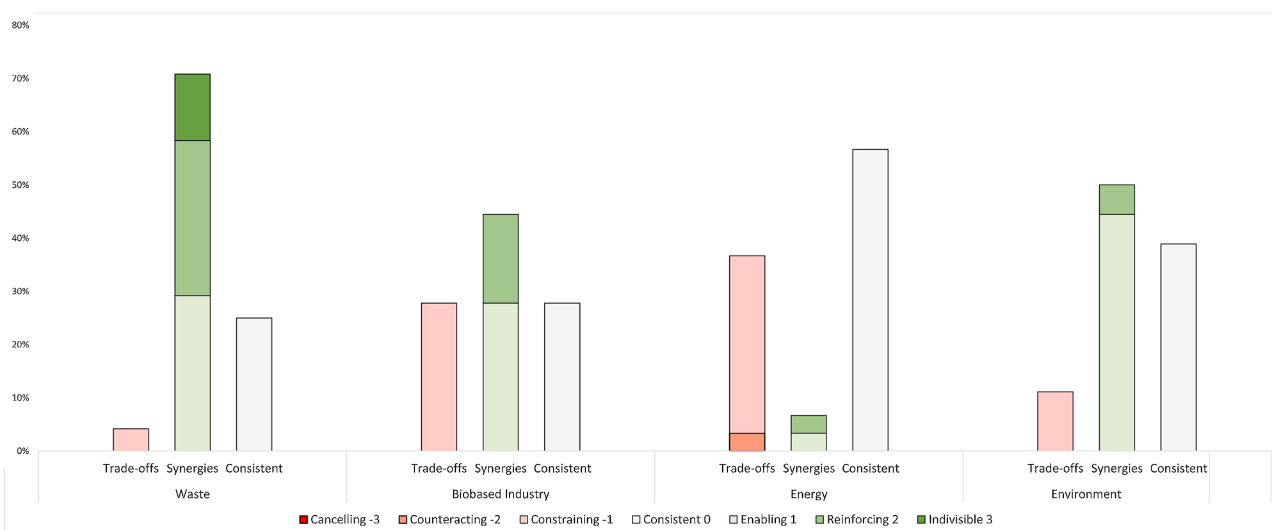


**Fig. 2.** Interactions (trade-off, synergy or consistent) between policy domains and agro-food policy. Size of bars shows the percentage of interactions with a given score while colour shows strength (positive/negative) of the coherence score.


**Fig. 3.** Interactions between bioeconomy and agro-food policy domains. Interactions are shown per each pair of goals. Position of circle indicates coherence score. Colour of circle indicates expert confidence (low, medium, high). Black lines indicate upper and lower ends of the coherence scores given by experts.

In this case, results indicate that bioeconomy policy goals are perceived to be largely consistent (meaning two goals do not interact) or synergistic (meaning two goals interact positively) with agro-food policy goals. While all four policy domains register synergies across all three possible synergistic scores (enabling +1, reinforcing +2, indivisible +3), trade-offs are weaker in strength. All policy domains have some trade-offs, with all policy domains having some goals that may be 'constraining' on agro-food policy. However, only the energy policy domain had some interactions that were counteracting. No two policy goals were found to be so incoherent as to be cancelling each other out. All policy domains also had many interactions that were considered to be consistent, meaning that the policy goals do no interact either positively or negatively. Waste policy has the largest potential for synergies with agro-food policy, while energy has the least potential.

Fig. 3 presents the results of the survey by presenting the coherence score, the range of scores and the confidence score for each pair of goals across the different policy domains. Fig. 3 indicates that the agro-food goals of ‘Food security’, ‘Reduce food waste’ and ‘Resource efficiency’ have the most synergistic effects, showing the more positive coherence scores than other agro-food goals. To reduce food waste, the waste goals ‘Reduce waste’ and ‘Cascade biomass’ have the most potential, with scores of 3 and 2.5 respectively. To improve resource efficiency, bio-based industry goals, such as ‘*Ban biodegradable landfilling*’, ‘*Utilising unused residues*’, can have synergistic effects. Decoupling environmental impacts from a growing economy was also assessed to have a synergistic effect on resource efficiency in the agro-food system. The agro-food goals with the most trade-offs were ‘Domestic and organic fertiliser’ and ‘Domestic protein crops’. Both goals entail increasing domestic supplies of biomass i.e. within the EU.

However, digging further into the results from the survey shows gaps and uncertainties in the knowledge-base. While the coherence scores show that bioeconomy and agro-food goals interact positively or do not interact at all, looking into the range of coherence scores (which measures expert disagreement) and the confidence scores (which measures expert confidence) gives a different picture. Fig. 3 below shows that relying on the coherence score alone may be misleading. The coherence scores frequently had large ranges even for interactions and policy domains that were scored with high confidence, for example, the effect of cascading biomass (Waste2) on healthy soils (Agro2). The reverse was also true, where experts all scored the same score but with low to

**Table 2**
Results of the focus groups. Qualitative descriptions of the interactions assessed between each policy domain (waste, bio-based industry, environment, renewable energy) and its effect on an agro-food goal.

| Goals | | Interactions identified |
|---|---|---|
| Effect of | On | |
| Waste1 ‘Adhere to the waste hierarchy and reduce waste generation’ | Agro4 ‘Domestic protein crops’ | Reducing waste might free up land that could be used for protein crops but only to a very limited extent. If the land is to be freed for protein crops, incentives are needed for efficient land use. |
| | Agro5 ‘Reduce food waste’ | The waste hierarchy states that wastes should be avoided and reduced, therefore there is a strong synergy between adhering to the waste hierarchy and reducing food losses and wastes. |
| Waste2 ‘Encourage the cascading principle taking into account all biomass-using sectors utilising biomass in the most resource-efficient way’ | Agro2 ‘Healthy soils’ | Cascading biomass may result in more by-products being directed to livestock feed and bioenergy over composting. The resulting products, manure and digestate prove easier to transport back to the soils where nutrients are needed. However, if a high market value is placed on a biomass stream such as crop residues, this could threaten soil conservation. This is dependent on the practices applied to prevent soil degradation and under what type of farming system: organic, agroecological, circular etc. |
| | Agro3 ‘Domestic and organic fertiliser’ | Cascading biomass may mean using more waste biomass as livestock feed and bioenergy, resulting in manure and digestate but at lower quantities and in a less stable state than composting. However, this is dependent on the priority that the cascading principle would place on organic fertiliser. |
| | Agro4 ‘Domestic protein crops’ | Reducing waste will free up land that could be used for protein crops but to a very limited extent. Freeing up land for protein crops requires incentives for efficient land use. In addition to above, protein-rich by-products should be directed to livestock feed under a cascading principle. If a cascading principle puts a priority on directing residual biomass towards feed, this may potentially improve feed security. It would also not be enough to address the current feed dependency. |
| | Agro5 ‘Reduce food waste’ | Cascading biomass would mean that certain biomass streams will be utilised, translating into fewer food wastes and losses. There is a strong synergy between the cascading principle and reducing food losses and wastes. |
| Waste3 ‘Recover energy only from non-recyclable materials’ | Agro2 ‘Healthy soils’ Agro3 ‘Domestic and organic fertiliser’ | This is dependent on whether biomass is considered a recyclable material. Since it is likely a recyclable material, this may limit bioenergy and incentivise the use of biomass for soil fertilisation. |
| Waste4 ‘Ban landfilling of biodegradable waste by 2025′ | Agro1 ‘Food security’ | Banning biodegradable waste may mean that there is an incentive for these biomass streams to be converted into food and feed, which may help food security. However, if these biomass streams are incinerated than there is no link to food security. |
| Goals | | Interactions identified |
| Effect of | On | |
| BIO2 ‘Develop new bio-based products and materials’ | Agro3 ‘Domestic and organic fertiliser’ | The development of new bio-based materials may compete with the production of organic fertiliser, particularly because in the initial phases of development of bio-based products, the more raw material is needed. |
| BIO4 ‘Replace fossil-based products with bio-based, recyclable and marine-degradable products’ | Agro3 ‘Domestic and organic fertiliser’ | The development of new bio-based materials may compete with the production of organic fertiliser, particularly because in the initial phases of development of bio-based products, the more raw material is needed. Developing a bio-based product that is marine degradable may also need more raw material in the initial phases of development. |
| BIO5 ‘Facilitate the development of new sustainable biorefineries’ | Agro3 ‘Domestic and organic fertiliser’ | The development of new biorefineries may create competition across different biomass applications, such as with the production of organic fertiliser, particularly because in the initial phases of development of bio-based products, the more raw material is needed. |
| BIO6 ‘Changes in consumption promoting healthier and more sustainable diets’ | Agro4 ‘Domestic protein crops’ | Given current consumption patterns, increasing domestic protein crop production while maintaining the same levels of animal-source food consumption will likely come with negative environmental effects. On the other hand, if the production of domestic protein crops is matched with lower livestock demand, such for example, feeding livestock only by-products of crop production, these goals may be coherent. |

medium levels of confidence (e.g. BIO2 on Agro3). Concerning the range, there were only a few interactions where all experts converged to the same score, these were: BIO2 'New bio-based products' on Agro3 'Domestic and organic fertilisers', Energy4 'Halt indirect land-use change' on Agro5 'Reduce food waste' and Energy5 'Biofuels on marginal land' on Agro5 'Reduce food waste'. Nevertheless, ranges of scores for most policy domains were particularly high within the environment policy domain, particularly for Env1 goal of 'Decoupling and for the Waste and Bio-based industry policy domains concerning Waste2 'Cascade biomass' and BIO6 'Healthy and sustainable diets'. Hence, and despite the median would show a consistent coherence score, the ranges provide a wider and sometimes conflicting picture. This could be because there is a great deal of uncertainty around the feasibility of achieving some goals (e.g. decoupling) or to different interpretations of the goals and imaginaries on how to achieve those goals. This is further discussed below in Section 4.

Concerning the confidence score, the policy domains with the highest confidence were waste, energy bio-based industry, particularly when assessing the effects of such policies on food security and reducing food losses and waste. This may reflect that scientific knowledge surrounding these politically high priority goals may be higher than for newer and more specific goals such as Agro3 'Domestic and organic fertiliser. This may also reflect the large knowledge-base, particularly in the case of energy, regarding the conflict between bioenergy production and food security and conflicts around biomass more broadly. However, both waste and bio-based industry were the only policy domains that had interactions with low confidence; concerning the effect of promoting domestic and organic fertilisers. When speaking to experts, it became clear that this was because the knowledge-base concerning bio-based industry is still limited (Table 2).

To gain insight into possible explanations from experts about the ranges in coherence scoring and the certainty in the answers we organised focus groups that presented the interactions from the survey where experts mostly agreed (low range) or disagreed (high range). Supplementary Table 2 presents the results of the focus groups. The focus groups revealed that a complex set of interactions is often taking place between two goals that could not be fully captured with the coherence score. As explained above and shown in Fig. 2, overall interactions were synergistic or consistent when considering coherence scores only. However, digging into the interactions with experts revealed that some goals may interact in multiple, sometimes opposing ways. Even for pairs of policy goals that were scored as consistent, interactions were identified that could potentially change the coherence score if the context would change in the future. For example, in the case of the effect of the bio-based industry goal '*Changes in consumption promoting healthier and more sustainable diets'* on the agro-food goal '*Increase domestic protein crop production especially for livestock feed',* was highly dependent on the degree to which sustainable and healthy diets could be achieved in the future. It furthermore depended on how a healthy and sustainable diet is defined and the amount of animal-source food in the diet. This revealed that coherence scores depended on several factors. Firstly, it revealed uncertainties, particularly about resource use or consumption patterns into the future. Other uncertainties concerned the feasibility of some solutions which remain, as yet, unproven or disputed. The focus groups furthermore revealed contextual factors: the agriculture practice or agricultural system, the temporal or geographical, or biophysical scale within which a policy is implemented. Furthermore, focus groups revealed some interactions were difficult due to the vagueness in the definition of policy terms. We address such wider issues in turn below.

## 4. Uncertainty, knowledge gaps and contextual factors

Despite finding that bioeconomy policy and agro-food policy is largely consistent or synergistic when considering the coherence score only (Fig. 2) it is also clear that there is significant uncertainty and disagreement amongst experts, particularly for some policy goals such as 'Domestic and organic fertiliser' and domains such as environment. This means that policies surrounding the bioeconomy are considered coherent for the most part in trying to balance the various biomass applications but many uncertainties and questions remain.

The focus groups revealed three uncertainties; first the feasibility of decoupling environmental impacts from economic growth, second, the future use of land and third, future human diets. Decoupling can be defined as either relative when economies grow faster than the rate of resource use and environmental impact, or absolute, when resource use and associated impacts decline in absolute terms irrespective of economic output (Ward et al., 2016). The range of score reflected disagreement on the possibility and extent to which decoupling is feasible, particularly on the debate on whether relative or absolute decoupling is possible (UNEP, 2014). Experts believed that so far, economic growth, material use and environmental impacts have gone hand-in-hand (O'Neill et al., 2018) and it is difficult to imagine a future where decoupling, particularly the absolute decoupling of environmental impacts from economic growth, would be possible. Such discussions reflect current scientific debates around the possibility of decoupling (Giampietro, 2019; Hatfield-Dodds et al., 2015; Wiedenhofer et al., 2020), which have a long history in the wider question of whether environmental and economic goals can ever be reconciled. However, all experts agreed that if decoupling could be achieved, it would benefit all agro-food goals, particularly food security, soil health, reducing food losses and wastes and improving resource efficiency.

The future use of land was another source of uncertainty, where experts cited that this depended on future consumption patterns and the possibility of sustainable intensification and improved crop productivity. Projected future land use is at the heart of many agricultural, energy and climate models (Alexander et al., 2017; Prestele et al., 2016). It is also often cited as a key uncertainty in these models as land use depends on several factors, such as socio-economic and political aspects, consumption patterns and crop productivity (Holman et al., 2017). In the case of sustainable intensification, experts argued that this could reduce overall land-use but could come with trade-offs, such as impacting soil quality. In the case of improved crop productivity, experts cited considerable improvements in crop productivity in past years (Ritchie and Roser, 2019) and questioned the degree to which such a trend could continue (Ray et al., 2013; Zhao et al., 2017).

Closely related to land use, the successful implementation of some goals depended to a large extent on future human diets and consumption patterns, particularly the amount of animal-source food (ASF) in human diets. The transition to sustainable and healthy diets and its relation to increasing domestic feed crops for livestock in Europe, for example, (BIO6 on Agro4), depended to a large degree on the amount of ASF in human diets. Diets high in ASF are associated with higher land use (Gerbens-Leenes and Nonhebel, 2002; Ranganathan et al., 2016; Van Kernebeek et al., 2016; Van Zanten et al., 2019, 2018) and would therefore likely reduce the amount of land available to plant protein crops. Meeting livestock feed demands with domestic resources would be particularly difficult because the EU livestock sector is dependent on feed imports (de Visser et al., 2014; Lywood et al., 2009). However, a key opportunity for synergy between these two goals could be achieved if consumption patterns shift away from animal-source foods. If livestock are fed with by-products from food production and grasses, this could reduce land use and provide a domestic source of protein for livestock (Van Zanten et al., 2019).

It is difficult to overcome many of these uncertainties as they often depend on socio-economic and political drivers, particularly in the case of human consumption patterns, which may be difficult to predict. Nevertheless, these uncertainties point towards knowledge gaps in research. For example, it remains largely unknown how decoupling can be achieved, particularly in the context of the bioeconomy because it reintroduces increased dependence on natural resources (Giampietro, 2019). Moreover, knowledge is still limited on how the livestock sector can contribute to the bioeconomy; potential exists for scoping domestic sources of feed that improve nutrient cycling and reduce land use but further research is needed (Van Zanten et al., 2019).

As governments around the world and international organisations aim for increased coherence to meet multiple sectoral goals, science will be called upon to provide a robust knowledge-base. However, this will mean that both science and policy will have to contend with increased complexity as they seek to govern systems that cannot be predicted by studying the components that make up these systems (Geyer, 2012; Kovacic et al., 2019; Strand, 2002). This will entail dealing with uncertainty, of which we identify different types following Kovacic et al. (2016), namely technical uncertainty, which is uncertainty emerging out of practical issues, methodological uncertainty, having to do with how phenomena are analysed, and epistemic uncertainty, having to do with how knowledge is framed and defined.

The uncertainties presented in this study depended on a number of contextual factors, namely implementation, temporal scale, geographical scale, and definition. We relate these factors to different types of uncertainty. The policy goals presented above are goals as stated in policy documents, however, implementing these goals will require a range of different agricultural and environmental practices. The degree to which these practices are implemented points towards technical uncertainty, as there is no guarantee whether or how these practices may be implemented. To prevent soil degradation and restore soils, for example, many different practices may be employed, such as crop rotation and no-till practices (Bai et al., 2018). Experts also emphasised that the interaction between goals will operate differently depending on the agricultural system. While some goals may be conflicting under current agricultural systems this may not be the case in the future if systems move towards other forms of farming, e.g. organic farming, circular food systems or farming based on agroecological principles (de Boer and Van Ittersum, 2018; FAO, 2016).

Temporal scale, that is the time over which two policy goals may interact, was also considered as important. Experts believed that some policy goals, such as preventing soil degradation, will become more important in the future, particularly if current rates of soil degradation continue (Gomiero, 2016). In the case of soils, experts believed that many other goals depended on healthy soils, particularly food security. The extent of soil degradation, currently and into the future, similar to projected land use, is a key source of uncertainty in predicting future food systems (Gomiero, 2016). Temporal scale will be particularly important for those interactions that do not take place in the short-to-medium term but appear after a significant time lag. Policy interactions also depend on the geographical scale, both in terms of implementation and in terms of effects. Firstly, interactions depend on where the policy goals would be implemented. For example, experts argued that while the Netherlands may have enough manure available to meet both energy and soil fertility needs, this might not be the case elsewhere in Europe. Experts also doubted whether the effects of EU policies outside of the EU should be considered in the assessment. Experts argued the production of food waste in EU countries and their notable role in food trade (Porkka et al., 2013), affects the food security of countries elsewhere by externalising the environmental impacts of food production (Chaudhary and Kastner, 2016; Lambin and Meyfroidt, 2011; Meyfroidt et al., 2010), thereby degrading agricultural resources needed to produce food for local markets. However, the knowledge base of the effect of food waste in developed countries on the food security of food-producer countries in the Global South is still under-researched but some studies indicate lower-food waste in developed countries may provide economic benefits in developing countries (Ishangulyyev et al., 2019). Furthermore, food that is unwanted in EU countries due to consumer preferences may be exported to developing countries where they disturb local markets (Murphy and Hansen-Kuhn, 2019).

For some domains, particularly that of energy, experts felt that while policies could be coherent at a local level, once upscaled, any synergistic effects may be reversed. In the context of waste and residue-based biofuels, synergies could be observed at a local scale. For instance, waste and residue-based biofuels or 'advanced biofuels' have the potential to avoid sustainability issues associated with conventional, food and feed crop-based biofuels, such as land-use change, increased greenhouse gas emissions and induced higher food prices (Persson, 2013; Popp et al., 2014; Steinbuks and Hertel, 2016). In the case of conversion of wastes, such as municipal wastes and manure, into biogas, this can have the dual advantage of providing both energy and organic fertiliser and offsetting greenhouse gas emissions from manure storage (Bidart et al., 2014; Parajuli et al., 2018; Tonini et al., 2016). However, the degree to which the renewable energy target can be supplied by advanced biofuels is limited. This is due to several factors, such as the limited supply of wastes and residues, other competitive uses for these residues (Styles et al., 2015; Tufvesson et al., 2013) (e.g. feed, application to soil) and high energy and infrastructural requirements to collect wastes and residues. Furthermore, experts questioned whether bioenergy *should* be based on wastes and residues, given that following the waste hierarchy, the first incentive should be to avoid the production of wastes.

We found a wide range of scores associated with terms with unestablished definitions, such as the 'cascading principle'. Issues of definition point towards uncertainty of an epistemological nature where how the scientific analysis or policy goal is framed determines the knowledge acquired. This can be seen for example in the interaction between *'Encourage the cascading principle taking into account all biomass-using sectors utilising biomass in the most resource-efficient way'* and *'Preventing soil degradation'*. While the general principle behind the cascading principle is understood as utilising biomass at its highest utility, there is uncertainty about what highest utility may imply, particularly which biomass use corresponds to the highest utility. The strong synergy between the waste hierarchy and the reduction of food losses and wastes (Waste1 on Agro5) may indicate that having a clearly defined order for the utilisation of biomass (waste in this case), can have beneficial effects. This also points towards the vagueness in the definition of policy goals, which means that effects largely depend on context and implementation rather than the coherence between different policy domains. Confidence levels, for example, were particularly low for waste and bio-based industry policy domains when scored against Agro3 'Domestic and organic fertiliser'. The lack of clarity regarding what it means to cascade biomass (Waste2), sustainably scale biomass supplies (BIO1) or develop biorefineries (BIO5) led to low scores of confidence. Issues of scale, temporal, geographical and biophysical depend greatly on the nature of the analysis, particularly with the challenges of estimating interactions separated by time and space. Issues of scale, therefore, point towards methodological uncertainty.

## 5. Discussion

The aim of our study was twofold: to assess the potential effect of bioeconomy policy domain on agro-food policy by presenting whether they are coherent (trade-offs, synergies) and mapping out key interactions and uncertainties. Figs. 2 and 3 and Table 2 present the results of our survey and focus groups conducted with experts. The overall results indicate that when considering the coherence score, policies can be considered coherent and that synergies largely outweigh trade-offs. However, digging further into the range of scores and confidence levels by experts, the picture becomes more complex. The inclusion of both range of scores and confidence levels allowed us to see both where there are knowledge gaps and uncertainties (confidence) and where experts may have high confidence but disagree (range). We suggest that these measures of uncertainty and disagreement be included in future assessment of policy coherence. It should be noted that an important limitation of our research is that it only studies the coherence between policy goals thereby assessing the potential effects if these policies were implemented *perfectly*. This study therefore does not represent an assessment of the efficacy of the policies and/or their implementation. Extending this analysis to the tools used to achieve these goals is necessary for better implementation and coherence. However, this was beyond the scope of this study.

The knowledge base regarding policies is more certain around high-priority goals such as food security and the reduction of food waste, particularly between the waste, energy and bio-based policy domains. Our results show that key knowledge gaps remain in the waste and bio-based policy domains, particularly due to the gaps in the knowledge-base around biorefineries, bio-based products and how to increase domestic organic fertiliser. Experts particularly disagreed regarding the possibility of decoupling economic growth from environmental impacts and the possible impacts or benefits of healthy and sustainable diets.

However, sometimes disparity in expert opinion could be explained through the lack of definition and vagueness of terms/goals. We have shown that this vagueness makes it difficult to assess the coherence of these policy goals as their coherence depends on several contextual factors such as temporal and geographical scale which will affect implementation. This raises the question, what does policy coherence mean in the context of this study? We argue that assessing policy coherence is not as straightforward as matching policy goals with scientific evidence (International Council for Science, 2017; McCollum et al., 2018). To this end, frameworks have been proposed such as the 'water-energy-food' nexus to overcome silo, top-down, linear governance models. While initiatives to move away from policy silos to more integrative policy approaches (e.g. the 'nexus' approach) should be lauded, initial evidence indicates that more will be needed to overcome these silos in institutional settings (Voelker et al., 2019). This indicates that overcoming such silos will require more than technical fixes (Voelker et al., 2019). As argued below, this will mean overcoming vague terms for better assessment. Other studies have shown how undefined terms in policy may aid the political process (Candel et al., 2014; Kovacic and Di Felice, 2019), however, a distinction needs to be made between ambiguity and vagueness. Our study has found both ambiguity rising out of uncertainty and vagueness; following Kovacic and Di Felice (2019), we differentiate between vagueness in policy goals, which may serve political purposes, and ambiguity, which arises necessarily out of the complexity, uncertainty and incommensurable frames in scientific knowledge. Vagueness should be overcome with better definitions. Ambiguity, on the other hand, may broaden the space for a multitude of stakeholders and innovations to take hold (Kovacic and Di Felice, 2019; Termeer and Metze, 2019). However, this may go against the expectations of some institutional actors who may expect quick, deep, top-down transitions (Termeer and Metze, 2019) and may explain why 'overcoming silos' has so far not been fully successful (Voelker et al., 2019).

### *5.1. Insights and recommendations for science and policy*

The presence of trade-offs between bioeconomy policy domains and agro-food policy domains shows that scientists and policy-makers will need to overcome 'silo-thinking' to find integrative solutions. However, our results point towards silo-thinking being difficult to overcome since policy success will depend greatly on how goals are defined and particularly on context-dependencies such as temporal and geographical scale. Science is furthermore either replete with uncertainty regarding some issues (e.g. potential effects of bio-based industry) or with disagreement (e.g. decoupling). It is therefore imperative that specific policy domains are designed with potential interactions with other policy goals in mind. Furthermore, increased awareness is needed that overcoming 'silo-thinking' is more than a technical issue as argued above. The best way forward may be in overcoming vagueness, by better defining terms, and embracing ambiguity, which allows for different stakeholders to take part in a transition towards a bioeconomy.

Vagueness, for example, can be overcome in the case of the cascading principle. While the EU has clear guidelines for the various uses of waste biomass, there are no such clear guidelines for biomass in general. The waste hierarchy, as defined in the Waste Framework Directive (Directive 2008/98/EC, 2008), states that waste biomass must be utilised for different purposes before being used for energy. The cascading principle, which aims to direct biomass towards its highest utility use to boost resource-use efficiency, does not yet have a clear definition. More importantly, incentives in renewable energy policy, particularly in the Renewable Energy Directive (European Parliament, 2009), direct biomass to energy use first. For example, the double-counting mechanism, which counts the energy content of waste-based biofuels twice towards the renewable energy target, incentivises biomass towards energy use before other uses (Birdlife Europe and European Environmental Bureau, 2014; Dammer and Essel, 2015). In practice, this may lead to competition issues between other uses of residues, e.g. crop residues could be utilised to maintain and improve soil health. Acknowledging these biomass competition issues can help break down the 'silo' surrounding the Renewable Energy Directive. Furthermore, there is a clear trade-off between making a goal-specific, allowing for clear implementation and assessment and making a goal broader to gain political agreement and allow space for various solutions (Candel et al., 2014; Kovacic and Di Felice, 2019). However, from this assessment, it is clear that some terms would benefit better definition and better integration between the various policy domains. The EU would benefit from having general guidelines for the cascading of biomass, beyond that specifically related to waste. Our results show, that if well implemented, proper cascading use of biomass could create synergies and improve soils, food security and reduce food losses and wastes.

Furthermore, increased awareness is needed about the limitations of some solutions. While waste and residue-based biofuels or 'advanced biofuels' have the potential to avoid sustainability issues associated with conventional biofuels the degree to which the renewable energy target can be supplied by advanced biofuels is limited. It is therefore imperative that the scale to which technologies can solve sustainability issues is communicated between science and policy.

Finally, our results have relevance for governance as policy shifts away from silo approaches and to more integrative policy-making, such as the Sustainable Development Goals or the water-energy-food nexus. The multiple sources of uncertainty, spanning across different types of uncertainty, namely technical, methodological and epistemic, mean that the relationship between science and policy should not be treated as a puzzle-solving exercise. Instead, a more flexible approach should be taken to decision-making that adapts to difference scales, contexts and practices. The science-policy interface under a 'silo' approach was characterised by a linear relationship between science and policy, where science presents the facts and policy defines goals accordingly. However, recognising the interlinkages between different policy sectors means that governance will have to take place under uncertainty and thereby complexity (Kovacic et al., 2019).

## 6. Conclusions

Our research shows that considering the coherence score only, bioeconomy and agro-food policy could be considered either synergistic or not interacting by experts. Overall, the waste policy domain provided the most opportunity for synergies with agro-food goals. The agro-food goals of food security and reducing food waste have the most potential for synergies if other goals such as reducing waste, using underutilised residues and cascading of biomass are achieved. Our inclusion of experts' disagreement, confidence, as well as focus groups, however, revealed that policy interactions may be more complex. The knowledge base is more certain around goals such as food security and reducing food waste but less so around the increase of domestic organic fertiliser. Particularly, our policy coherence analysis revealed key uncertainties such as projected future land use, future human diets and the feasibility of decoupling. This left room for ambiguity and vagueness. We argued that ambiguity was largely associated with the complexity of the issues, while vagueness with undefined policy terms. We conclude that vagueness in policy may be overcome through better definition of terms, particularly that of the cascading principle, which has a high potential for synergies with agro-food policy. However, “nexus” policy requires also working within uncertainty and adapting policy to different contexts, temporal and geographic scales, and implementation practices, rather than pursuing universal fixes.

## Author statement

Abigail Muscat, Raimon Ripoll-Bosch, Evelien de Olde, Zora Kovacic: Conceptualisation. Abigail Muscat: Data curation, formal analysis and visualisation. Abigail Muscat: Original Draft preparation. Raimon Ripoll-Bosch, Evelien de Olde, Zora Kovacic: Supervision, Review and Editing.

## Declaration of Competing Interest

The authors report no declarations of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.envsci.2021.05.001.

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