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ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

Editorial

CAP, Farm to Fork and Green Deal: policy coherence, governance, and future challenges

Annalisa Zezza

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The European Green Deal sets very ambitious high-level goals in terms of growth and environment, with the aim of turning the EU into a modern, competitive, and sustainable economy. The objective is to reach the target of zero carbon emissions generating greenhouse effects by 2050, the "decoupling" of economic growth from the use of natural resources, and a wider social inclusion for people and territories. To pursue such an ambitious plan, the Green Deal laid out a series of objectives and actions to ensure that every sector of the economy gives its contribution. This approach should be able to translate the Green Deal ambition into a system of complex sectoral-level policies that interact with each other for the achievement of the common high-level goals. However, the extent to which this complex system will be effective in achieving these goals will depend on policy coherence and on governance.

The 11th AIEAA annual conference entitled "CAP, Farm to Fork and Green Deal: policy coherence, governance, and future challenges" has been an occasion to explore the potential synergies coming from the integration of the CAP with other EU and national policies under the Green Deal umbrella. By gathering together scholars with different points of views and academic backgrounds, the Conference aimed to improve the understanding on how to reach an increased policy coherence and integration, explore new holistic governance approaches to the agri-food system, analyse the impact on the national and local systems and look to future challenges.

In this context, a new generation of complex transformative policies is needed and the first paper, by Gianluca Brunori (2023) gives a valid contribution in finding an answer to some very important questions such as "*What are the qualities that a new generation of policies should have? What should be done to foster a new generation of policies?*". Transformative policies are characterized both by a multiplicity of actors and complex sectoral interconnections. Considering that both the design and the impact of transformative policies depends on the characteristics of socio-technical and socio-ecological systems, new knowledge, new approaches and new forms of dialogue and governance are needed.

The second paper in this issue by Silvia Coderon (2023), focuses on the trade of between Food security and environmental sustainability as a 'false dilemma' that may delay the urgent action needed to establish a coherent policy framework that could help in meeting the ambitious challenge of making agriculture and food systems more environmentally sustainable. Nevertheless, the policy objective to increase food security while reaching higher environmental sustainability standards is very difficult to achieve as it raises multiple policy coherence and related governance problems. The author distinguishes between 1) a 'within-policy coherence' when public policy efforts are not directed towards the needs of the sector, and 2) 'between-policies coherence' when different policy objectives receive different degrees of policy support or even contradict each other, presenting governance issues related to this complex challenge. With regard to 1) the author stresses the need (and the challenges) for a more targeted CAP including the need for space based data for better policy design, implementation and monitoring. With regard to 2) the author highlights the impact on the agrifood system of policies including the LULUCF regulation, the Effort Sharing Regulation and the EU Emission Trading System, which has an impact on the entire food supply chain. Three

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major challenges are discussed i.e. the incurrence of high transaction costs to detect the synergies and trade-offs between policy objectives, the dependence of synergies and trade-offs on the different instruments chosen, and the need to arrive at value judgments on the different interests involved.

The next two papers explore some emerging issues at the local level. The contribution from Fasano and Pagliacci (2023) analyses how the valorization of high-quality agri-food products through the use of geographical indications impacts on the economic development of inner areas. They use municipality-level (LAU2) data and apply hurdle models to assess the effect on several variables such as agriculture and food industry features, socio-economic characteristics, regional settings. Their results suggest that across inner areas geographical indications still represent a sort of untapped resource that, to be effective would require a more effective policy intervention, recalling the "between policies coherence" suggested in the first paper,

The paper from Tappi and al. (2023) analyses the impacts of extreme weather events on crop production demonstrating how heterogeneous those effects can be accordingly to the types of crops. The results imply that farmers and policymakers may adopt ex-ante and ex-post risk management strategies taking into account thus variability, adapting solutions to the local scale

As stated by Brunori (2023), in the opening essay, a new generation of policies implies a new generation of scholars that experiment new models of collaboration between policy-makers and researchers. Our hope is that the AIEAA Conference has been a step in opening the way to a new generation of agri-food policy researchers that assign increased attention to socio-technical and institutional mechanisms that regulating food systems, by adopting a a stronger interdisciplinary approach.

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Keynote speech of the 11th AIEAA Conference

Key policy objectives for European agricultural policies: Some reflections on policy coherence and governance issues

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Abstract. Food security and environmental sustainability are global challenges that must be addressed together to be solved. After stressing the importance of solving the challenges of producing enough food to feed a growing population while preserving the climate and the environment, this analysis discusses some issues related to the policy coherence (PC) approach that should be followed. Within-policy and between-policies coherence problems are assessed and discussed, and governance problems related to the PC approach are presented. Key points for a likely approach to PC include goal-based governance grounded in the analysis of synergies and trade-offs.

Key Words: policy coherence, agricultural policy, environmental sustainability, food security, governance.
JEL codes: Q15, Q18, Q57, Q54.

HIGHLIGHTS

- Food security and environmental sustainability should be tackled jointly
- Policy coherence is central to achieving food security and environmental challenges
- Within and between coherence policy problems are discussed
- Synergies and trade-offs should be analytically assessed and made explicit
- A goal-based governance should be deployed

1. INTRODUCTION

The European Green Deal (European Commission, 2019) has confirmed the environmental ambition, stated in 2011 (European Commission, 2011), to transform the European Union (EU) into a climate-neutral society with no net emissions of greenhouse gases (GHG) by 2050. This ambitious target makes the EU agriculture and forestry sectors pivotal in helping to reach climate neutrality as they are the only economic activities that can naturally store carbon in soil and biomasses, thus helping neutralise GHG emissions that cannot be reduced (European Commission, 2021). Along this line, the Council and the European Parliament have recently reached a provisional political agreement on strengthening the contribution of the land use, land use change, and forestry (LULUCF) sector to the EU's increased overall climate ambition.[1]

As a core part of the EU Green Deal, the 'From Farm to Fork Strategy' (F2F) was released in May 2020 to establish the required legislative framework to meet the challenges of sustainable food systems by reducing the environmental footprint of EU food, recognising that the health of people, societies, and the planet are deeply intertwined (European Commission 2020a). The strategy establishes severe environmental targets to be reached by EU agriculture by 2030, coupled with those established by the EU's biodiversity strategy aimed at putting biodiversity on a path to recovery by 2030 (European Commission 2020b).

This environmental ambition for agriculture is also found in the 2023–2027 Common Agricultural Policy (CAP) objectives (Regulation (EU) 2021/2115) as the newly established CAP should be, at least in the Commission's view, a key tool for achieving the ambitions of the F2F and biodiversity strategies.

However, the likely effects of these environmental commitments on food production and their socio-economic effects on farms and rural territories may be quite negative, raising food security (FS) concerns and highlighting the trade-off between economic and environmental objectives (Beckman et al., 2021; Barreiro-Hurle et al., 2021, 2022; Cortignani and Coderoni, 2022). FS worries, indeed, have surged to the top of (also) developed countries' policy agendas, mostly because of the compounded effects of conflicts, the COVID-19 pandemic, and climate change, which have set back years of improvement in FS globally (FAO, IFAD, UNICEF, WFP, WHO, 2021).

This study, first focuses on whether needing to choose between FS and environmental sustainability (ES) is a 'false dilemma' (Section 2) that may delay the urgent action needed to establish a coherent policy framework that could help in meeting the ambitious challenge of making agriculture and food systems more environmentally sustainable. Then, it also reflects on some issues pertaining to the complexity of establishing the policy coherence (PC) framework needed to meet this challenge. In particular, it focuses on what are defined here as '*within-policy coherence*' (*within PC*) problems, i.e. when public policy efforts are not directed towards the needs of the sector, and '*between-policies coherence' (between PC)*, i.e. when different policy objectives receive different degrees of policy support or even contradict each other. Governance problems related to this complex challenge are also presented (Section 3). Finally, issues related to PC approaches are discussed (Section 4), and concluding reflections are presented (Section 5).

2. KEY OBJECTIVES OF EUROPEAN AGRICULTURAL POLICY: A FALSE DILEMMA?

Providing FS and nutrition for a growing global population and contributing to ES while supporting livelihoods for workers along the food supply chain is globally recognized as the threefold challenge facing the agricultural and food sector (OECD, 2021a). This complex challenge also exists at the EU level, where ES issues have recently been placed firmly at the core of the policy agenda with the Green Deal strategy launch. Indeed, the EU explicitly declares to be willing to become a global leader in the fight against climate change and environmental degradation, leading by example, setting standards for sustainable global value chains, and using diplomacy, trade, and development cooperation to advance climate action.[2]

These ambitious commitments have been established through the EU legislative process that, over the years, has increasingly embedded the principles of better regulation (Listorti et al., 2020), including the stakeholders' engagement. In particular, in the context of EU agricultural and rural policies, also to address the concerns related to legitimacy, besides the co-decision mechanism, the EU has strengthened its approach to evidence-informed policymaking (EIP)[3] and civil society dialogue through a stakeholders' consultation approach and a system of impact assessment. As regards the stakeholders' engagement, the public consultation 'Modernizing and Simplifying the CAP' has highlighted that society identifies farmers as suppliers of healthy and safe products while also being responsible for protecting the environment and ensuring

[1] https://www.consilium.europa.eu/en/press/press-releases/2022/11/11/fit-for-55-provisional-agreement-sets-ambitious-carbon-removal-targets-in-the-land-use-land-use-change-and-forestry-sector/ (Accessed in November 2022).

[2] European Commission Communication on the 2019 Climate Action Summit hosted by the United Nations Secretary General in New York, doi:10.2775/171146.

[3] EIP is an idea in public policy proposing that policy decisions should be based on, or informed by, rigorously established objective evidence (Baron, 2018).

animal health and welfare (ECORYS, 2017).[4] More recently, in the public consultation on the sustainable EU food system initiative, a large majority of respondents (92%) agreed that food production must become more sustainable to meet future environmental and climate change challenges (European Commission, 2022a).

Stakeholders' involvement is also increasingly used to derive overviews of relevant policy issues (Van Ginkel et al., 2020) and to set sustainability sciences into research projects (Hagemann et al., 2020; Menozzi et al., 2017; Neßhöver et al., 2013), as it raises the quality and significance of research by contemplating more thorough information inputs (Reed, 2008). In a recent analysis of the key policy questions for European agricultural and rural policies, Coderoni et al. (2021) used expert sampling to select who could provide the best information to achieve the study objectives, such as people who advocate, supervise, or guide agricultural-policy processes in high-level institutions. The stakeholders' engagement brought up two major broadly shared indications: *i*) future agricultural and rural policies should prioritise environmental and climate objectives, and *ii*) economic and environmental performances of agricultures should be pursued (and thus analysed) jointly. Eventually, one key policy objective was commonly agreed upon, i.e. the *'Provision of enough healthy food with minimal impact on the environment and reduced reliance on subsidies, increasing efficiency, climate change adaptation, and resilience.'*[5]

Among the proposed post-2020 CAP objectives, the environmental ones were deemed by stakeholders to be the most relevant. These findings were not surprising, although they came from a very different range of stakeholders (from policymakers and researchers to local government or farmers' union representatives), because they were in line with other much wider stakeholders' consultation (ECORYS, 2017; HM Government, 2018). Surely, the influence of the policy context must be considered, as the interviews were administered between May and June 2020, thus, on the same days the F2F and Biodiversity Strategies were released, and this might have influenced replies as the attention of the agricultural and food sector was, at the time, completely catalysed by those documents.

Subsequently, the war in Ukraine has raised global attention on FS, but, indeed, this conflict has contributed to exacerbating an already troubling situation, as in recent years, decades of progress towards improving FS globally have started to be undermined for the combined effects of conflicts, climate change, the COVID-19 pandemic, and related economic shocks. The COVID-19 pandemic alone contributed to the largest single-year increase in global hunger since 2000 (FAO, IFAD, UNICEF, WFP, WHO, 2021). Concerns around FS are thus firmly back into the policy agenda, even for developed countries. In this regard, also the European Commission (EC) has elaborated several short- and medium-term replies to boost (global) FS and support farmers and consumers with escalating prices, as the conflict in Ukraine has not only reduced the supply of key commodities but also further intensified the rise in food and input prices (such as energy and fertilisers).

The EC had initially declared that in Europe, the availability of food, feed and fertilizers was not a primary concern (for the short term), although there were concerns regarding affordability due to high market prices and inflationary trends (European Commission, 2022b). The main problems foreseen were in terms of impact on input (e.g. potash) flows to international markets in the short term due to the sanctions imposed on Belarus and Russia (JRC, 2022). However, some measures were taken at the EU and national levels to contrast the short-term effects, and the persistence of the war has reinforced the need for political responses. These responses range from the protection of consumers from rising energy prices (Sgaravatti et al., 2021), to some derogation to greening obligations by allowing for the production of any crops for food and feed on fallow land that is part of Ecological Focus Areas in 2022 while maintaining the full greening payment (European Commission, 2022c). Despite the Commission's assertion that this last measure should be aimed at aiding supply chains in becoming more resilient and sustainable, in accordance with the F2F strategy (European Commission, 2022d), there is no doubt that such approaches could undermine ES objectives (Morales et al., 2022).

These types of policy responses, hence, have once again brought attention to the 'eternal' (not only) agricultural policy dilemma of whether and how it is possible to reconcile the pursuit of FS without undermining ES (Haniotis, 2021). However, this is now a 'false dilemma', and arguing about it does not accomplish anything other than delaying the active response to the great challenge that this joint global issue poses.

The 'real' question ought to be whether we believe that FS goals can today be achieved without addressing ES challenges. There is no doubt that the question might be answered in any way other than 'no' after being rephrased in this manner. In fact, there cannot

[4] These findings have also been confirmed in the UK, were the vision of the Green Brexit – 'with at its heart profoundly different agricultural policies, which put the environment first' (HM Government, 2018) found general support from stakeholders for replacing the CAP system with support to public goods.

[5] For details on the results and approach followed please refer to Coderoni et al., 2021.

be FS without higher ES. First, climate change and biodiversity loss are major (actual and future) threats to FS (and food safety) (UN, 2015; Pörtner et al., 2021; Jarraud et al. 2012; Coderoni and Pagliacci, 2023; Lamonaca et al. 2021; Leal Filho et al. 2023). Thus it is not plausible to hope to tackle FS without tackling ES. Secondly, many studies demonstrate that higher ES levels can help to reach FS[6], e.g. showing that less air pollution leads to higher crop yields (Lobell et al., 2022), but also that there can be positive synergies between higher productivity and lower GHG emissions (Valin et al., 2013; Baldoni et al., 2017; Coderoni et al., 2015). In other words, food (and energy) security concerns should reinforce efforts towards ES and not weaken them. Indeed, at least in the EU, the political agenda in the first months after the war in Ukraine seemed to be consistent with this conclusion[7], and the EC, in its observations on the draft Strategic Plans (submitted before the war started), required further review to '*exploit all opportunities to strengthen the EU's agricultural sector resilience, reduce Member States' dependence on synthetic fertilizers and scale up the production of renewable energy without undermining food production; and transform their production capacity in line with more sustainable production methods*' (European Commission, 2022d)

However, the policy objective to increase FS while reaching higher ES standards is very difficult to achieve as it raises multiple PC and related governance problems, which are discussed in the following sections.

3. POLICY COHERENCE PROBLEMS

EU policy objectives dealing with FS and ES belong to different policy areas sub-ordinate to different authorities with partially contradictory interests. Thus, the issues related to the PC and the governance of a policy aimed at reaching both FS and ES are far than trivial. To build the best policy mix across all potential policy instruments, PC should consider all relevant synergies and trade-offs across all policy objectives since it is ideal for policies to minimize misalignments at all levels. Despite the potential advantages of a coherent policy, achieving it may be highly challenging.

Sources of policy incoherence can be different. For this analysis, to identify different sources of likely policy incoherence more clearly, it is distinguished among what is defined as a *within-PC* issue, i.e. when public policy efforts are not focused on what the sector would need (in this case, to achieve FS and ES jointly), and *between PC*, i.e. when distinct FS and ES objectives have varying levels of policy support or even directly compete with one another. Then, governance problems are analysed with reference to the establishment in the sector of a policy-coherent approach.

3.1. Within policy coherence issues

As regards the issue of *within PC*, the attention is here mainly on the role of the CAP, as it is the oldest and largest budget policy influencing the EU agricultural sector since the European Community foundation, although whether CAP expenditure brings any significant farmers' response is still a subject under analysis (Esposti, 2022a). The first source of policy incoherence within the CAP is that, even if the agricultural and forestry sectors are key to reaching the GD targets, the CAP is ultimately not an environmental policy. The CAP approach remains, in fact, an exception to the EU environmental policy in some fields, as the Polluter Pays Principle (PPP), which is one of the main EU environmental legislation cornerstones, is not always applied, according to the European Court of Auditors (2021). This is the case, for example, of diffuse water pollution or GHG emissions, also because the cost recovery principle is difficult to apply to pollution originating from diffuse sources - where it is tough to identify the polluter – as is the case for agriculture. In this respect, the EC has replied to ECA's recommendations that it will conduct a study by December 2023 to assess the potential of applying the PPP to GHG emissions from agricultural activities (European Commission, 2021).

The application of the PPP, however, is not so easy to deliver in the agricultural sector, not only because it is a diffuse pollution source that makes it difficult to identify the polluter, but also because it requires a clear definition of the environmental baseline that separates the 'polluter pays' (when this baseline is not respected) from the 'provider gets', i.e. when farmers must be compensated if they aid in the preservation of the rural environment and so create public goods desired by society.[8] In the CAP policy framework, it is assumed that this environmental baseline is given by cross-compliance. However, in the actual setting, the PPP is undermined by the political justification idea that direct payments are,

[6] See, among many others: Ginebra et al. (2022); Hawkins et al. (2021); Kakraliya et al. (2021); Li et al. (2023); Nguyen et al. (2022); Wang et al. (2021).

[7] With the foreseen possibility to increase the renewable energy targets under the 'Fit for 55' package, and the recently reached provisional political agreement on strengthening the contribution of the LULUCF sector to the EU's climate ambition.

[8] As noted already by the Green Paper on perspectives for the CAP in 1985 (COM(85)333).

in part, a recognition of the costs that society requires farms to bear through cross-compliance (Matthews, 2013). Cross-compliance consists of respect for statutory management requirements (SMR)[9] and the land's good agricultural and environmental conditions (GAEC)[10]. While all farmers must respect SMR, only farmers receiving CAP support must respect EU standards on GAEC. Thus, it could be argued that the cross-compliance does not constitute the environmental baseline if farmers who do not get direct payments are not expected to adhere to all its standards (namely, the GAEC). As suggested by Matthews (2013), attention should be thus given to whether this baseline is appropriate or should be revised, considering both the effects on environmental outcomes and the competitiveness of the farms.

Although the CAP is not an environmental policy, environmental concerns within the policy have risen in their relative importance over the subsequent reforms, and indeed the CAP has also helped to achieve environmental objectives, mainly through the agro-environmental policies (AEP) it entails (among others: cross-compliance, greening requirements and agro-environmental measures). However, farmers' responses to different AEP can be highly heterogeneous, as shown by many studies in this field (see among others: Arata and Sckokai, 2016; Bartolini et al., 2021; Bertoni et al., 2020; Chabé-Ferret and Subervie, 2013). These studies have generally estimated average treatment effects without exploring individual treatment effect heterogeneity. In this respect, machine learning methods have recently proven to be helpful tools for analysing the impacts of AEP (Bertoni et al., 2021) that can also help in assessing heterogeneous treatment effects (Stetter et al., 2022). Supervised causal machine learning techniques have also been used to analyse Italian farmers' responses to distinct AEP measures implemented within the CAP's 2015–2020 reform to estimate individual (farm-level) and group treatment effects (Coderoni, Esposti and Varacca, 2021). Results show high heterogeneity in farm responses, individually and across different farm subgroups, where geographical features and production specialisation seem to play a major role. Detecting this heterogeneity becomes critical for improving policy design since it further stresses the highly advocated need for a more targeted design of the CAP (Erjavec and Erjavec, 2015; Ehlers et al., 2021). In fact, targeting specific farm features through policy could aid in reaching the stated environmental objectives more efficiently through expenditure savings (while retaining the same environmental performance) or through better environmental performances (while keeping the same level of expenditure) (Esposti, 2022b).

The need for a more targeted CAP can also refer to the spatial nature of data used for policy design and implementation. Space can interfere with the measurement of data used to plan, implement, and monitor the CAP in two main ways: one is spatial dependence, that is, the possible correlation of the measures of environmental (and economic) performances across contiguous units; the other is spatial aggregation, that is, how aggregating farm units at some geographical scale affects these measures (Baldoni et al., 2023). In fact, the literature has shown that when spatial data are used, spatial dependence cannot be excluded (Baldoni and Esposti, 2020) and that spatial aggregation (i.e. aggregating farm-level data at some geographical scale) affects the measurements (Jansen and Stoorvogel, 1998; Wade et al., 2019). In particular, working at the macro level may result in wrong evidence if the true effect to be detected is one operating at the micro scale, since some farm-level determinants disappear through spatial aggregation while other determinants emerge (Baldoni and Esposti, 2020). From a policy perspective, this means that the scale at which policies are designed and implemented becomes critical to prevent incurring the so-called ecological fallacy (i.e. the reasoning failure that arises when an inference is made about an individual based on aggregate data for a group). This problem has also emerged in Italy, where studies on the productivity–environment nexus in agriculture have shown that this nexus is space and scale-dependent: it may disappear and change the direction of the relationship passing from farm-level to aggregate data (Baldoni et al., 2023).

This evidence represents a further issue for targeting as it highlights that the level (or scale) at which policies are designed, implemented and monitored is very relevant, and a more efficient policy should be targeted to the real needs of the different territories, being grounded on the proper indicators.[11] However, more micro-level targeting, which has proven to be more effective in environmental and economic terms, comes at a cost to poli-

[9] SMR are rules on public, animal and plant health, animal welfare, and the environment.

[10] GAEC standards are designed to prevent soil erosion; maintain soil organic matter and soil structure; maintain permanent grassland; protect biodiversity and ensure the retention of landscape features; protect and manage water.

[11] However, this does not necessarily imply a higher level of subsidiarity. In fact, the level of subsidiarity should be linked to the to the nature of the environmental problem and should be higher for those environmental problems that are more local in nature, and lower for those that are trans-boundary in nature (e.g. climate change). Then, once decided the proper level of EU intervention, the scale at which the policies are applied should depend on the eventual spatial issues characterizing the measurement of the problem.

cymakers, both in terms of information requirements and administration (OECD, 2021a). For example, Konrad et al. (2014) find that a more targeted approach at the parcel level can achieve reductions in nitrogen runoff at a lower cost, thus lessening the trade-off between economic costs and environmental benefits at the farm level. However, the additional cost of targeting may outweigh the benefit, and policymakers may prefer a less targeted approach, accepting a higher risk of trade-offs (see the next section).

In this respect, digitalisation offers plenty of new instruments for sustainability monitoring (Ehlers et al., 2021) and thus can help tackle the challenge of targeting and tailoring measures (allowing, among others, accounting for results-based schemes). Indeed, abundant data are already available but not fully exploited, as in the case of data from tractors that could be used to leverage more sustainable farm management (Mattetti et al., 2022).[12]

One last source of *within*-policy incoherence is the choice of the wrong policy instrument. Many studies have shown that counterproductive effects can result from the selection of an inappropriate policy tool (OECD; 2021a). To this respect, it is interesting to look at the results of the OECD PC analysis on agricultural policies, which has further confirmed that different types of policy support for the agricultural sector have different environmental implications, with the most detrimental ones typically observed for the coupled support, while decoupled ones deliver income support with minor economic and environmental costs (OECD, 2019a).

One last aspect regarding *within-PC* analysis is worth mentioning here. In fact, it could be argued that the multifunctionality paradigm, which states that most negative (and positive) agricultural externalities are 'non-commodity outputs' biologically embedded in agricultural processes (OECD, 2001), makes synergies and trade-offs between economic and environmental aspects and among environmental aspects '*biologically embedded*' in agricultural production. In this respect, the OECD has concluded that multifunctionality only becomes a real policy issue when there is a strong link between the commodity and the non-commodity output which cannot be altered and when there is a market failure. Even then, more targeted policies (rather than relying on production-linked support) should be preferred (OECD, 2003; 2008; 2021).[13]

3.2. Between policies coherence issues

PC is complex to apply in a context in which synergies and trade-offs exist among different policies targeted at different objectives. This is likely to occur in the agricultural sector, which is asked, on the one hand, to produce more food, feed, fibre, and energy, and on the other hand, to become more environmentally sustainable and climate resilient. As an example, looking just at the EU climate policy, within the 'Fit for 55' package of July 2021, which puts forward the legislative framework to reach 55% net emissions reduction by 2030, the proposals that will have the most influence on the agri-food system are the regulations on including GHG from LULUCF, the Effort Sharing Regulation, which covers agriculture, and the EU Emission Trading System, which has an impact on the entire food supply chain because it will cover not only emissions related to energy use and fertilisers but also emissions related to fuels used in buildings and transportation. Additionally, the so-called 'carbon farming', i.e. practices to increase the store of carbon in agricultural soils and biomasses, is a key component of the legislative proposal (COM(2022) 672) of November 2022 on a Union framework for the certification of carbon removals. Also, the Committee on Environment, Public Health, and Food Safety have developed initiative procedures focused on methane emissions, and the Parliament issued a resolution in October 2021 that emphasised the significance of emissions monitoring and called for the creation of a legal framework with reduction targets. In such a complex framework, *between-PC* analysis seems to be fundamental.

Three major challenges arise in achieving *between PC*: the incurrence of high transaction costs to detect the synergies and trade-offs between policy objectives, the dependence of synergies and trade-offs on the different instruments chosen, and the need to arrive at value judgments on the different interests involved (OECD, 2021a).

As regards the first point, attaining coherence across policies can be quite expensive as transaction costs are incurred when coordinating across a wide range of policy areas and, maybe, multiple levels of governance (see Section 3.3). The absence of knowledge about all potential connections, which may necessitate significant research and consultation to discover potential interactions, further increases the transaction costs of establishing a PC. In addition, aiming for complete coherence could result in indecisiveness or even decision-making

[12] Of course, other factors, such as the complexity of the of the measurement, data property rights issues, and costs of digitalisation should be considered as they could substantially hamper the uptake of a PC approach.

[13] In fact, if the non-commodity output can be delivered disjointedly, separate incentives for the marketable and non-marketable outputs should be provided. Otherwise, when a link is found, often it is relaxed or weakened, e.g. through changes in farming practices (as mentioned previously, many synergies and trade-offs can depend on the chosen tool). Thus, separate incentives should be put in place.

paralysis; thus, it might be more practical to aim for 'good enough' coherence (Vanheukelom et al., 2018) that could be reached by addressing the most significant trade-offs and synergies.

The second obstacle to achieving PC is represented by the evidence that trade-offs and synergies between different policy domains depend highly on the policy tools used. As a result, coherence faces an extra hurdle because mapping potential relationships depends on all the instruments used, although this could also represent a positive opportunity because judicious instrument selection can reduce trade-offs and increase synergies.

One significant example provided by OECD (2021a) of the importance of the tool chosen is the need to target GHG reduction by means of demand- or supply-side tools, e.g. taxes on types of food consumed (such as meat) or GHGs emitted. According to economic theory, in a closed economy, the results in terms of reductions in quantities produced (and consumed) should be the same whether the tax is charged to producers or consumers. However, environmental results can differ. In fact, if the tax is imposed on GHG emitted, then, typically, not only the total GHG but also the emissions intensity of production will fall, as farms will start investing in the less emission-intensive production method (to avoid decreasing production levels). The same result could not be obtained with an undifferentiated tax on specific food products category as it could only decrease the product's consumption unless the program could be able to differentiate the tax depending on the levels of emissions, e.g. with a carbon label (Canavari and Coderoni, 2020); this could, however, bring higher transaction costs. Thus, even though, in theory, demand-side solutions might be utilised to address supply-side issues and vice versa, policies should ideally concentrate on directly addressing externalities as targeted measures have proven to be more effective in reducing the same level of GHG emissions with a smaller decline in production. Demand-side policy interventions are, therefore, the most effective ways to address consumer externalities, while supply-side policies should be preferred to address production-related externalities (OECD, 2021a).

Finally, the third challenge is the choice between two or more desirable – but conflicting – outcomes that may be necessary while designing a policy. This refers to both the trade-off that emerges when a policy is publicly funded, as it entails either raising taxes or cutting spending on other programs, but can also refer to conflicting policy goals that can be pursued with different types of policies (e.g. producing more food or increasing the share of grasslands to provide carbon sinks). These types of choices are based on society's priorities; thus, decisions cannot be reduced to technical issues but involve value judgments (OECD, 2021a).

Solving these complex challenges is not a realistic policy objective, whereas trying to manage them more effectively is. To that end, the OECD has proposed guidelines to provide a practical strategy to ensure PC for food and agriculture policy challenges, building on OECD recommendations on PC for sustainable development (OECD, 2019a). These guidelines propose that simplification is the first step to be made. Then for the remaining complexity, the strategy aims to systematically test and quantify potential interactions, calibrate the policy mix, and make societal and transboundary trade-offs explicit to support conscious and open decision-making (OECD, 2021a).

As regards the first step, i.e. the reduction of complexity, according to a long tradition of economic theory, in principle, policy interventions should be limited to setting the level of playing, i.e. building the framework necessary for markets and communities to operate; correcting market failures (i.e. internalizing externalities and helping to provide public goods) and ensuring fair wealth and opportunities distribution (OECD, 2021a).[14]

Even eliminating complexity, some interaction effects between policies will surely remain, and policymakers need to have the tools to identify the nature and extent of such interactions. This identification stage can be divided into two gradual steps.

The first step is the preliminary screening process, which can be facilitated by several techniques, including regulatory impact assessments (RIAs) and stakeholder consultation processes. In this stage, a broad perspective is needed to identify *spillovers* since certain interactions may have an impact on present well-being, but it is also crucial to consider potential 'future' (i.e. inter-generational) interactions or 'elsewhere' (i.e. transboundary) effects (see Section 3.3) (OECD, 2016).

In the second step, the potential interactions found should be further scrutinized analytically to detect direct and indirect interactions and quantify them whenever possible. This scrutiny may entail simulations, discussions with experts and stakeholders, and analyses of statistical and experimental evidence (see, among others, Ronzon and Sanjuan, 2020; Verghaus and Hake, 2018; Breure et al., 2022). Many interactions can

[14] Public intervention is just one side of the actions needed to meet the FS and ES challenge. Businesses can in fact play a major role by at least minimising any adverse impact of their activities. In this respect, many initiatives included in the F2F and derived from the international context can help establish a common framework to help agri-businesses and investors contribute to sustainable development (see among others the OECD-FAO Guidance for Responsible Agricultural Supply Chains; OECD/FAO, 2016).

be found, but what matters for policy is whether these interactions are significant enough to justify changing existing regulations.

In this analytical task, if small or no interactions are found, the best way to proceed is simply to target instruments to the chosen political objective.

If interactions arise between policy objectives, the first distinction to make is among synergies and trade-offs among them. When synergies occur between objectives, it should be kept in mind that 'silver bullets' rarely exist, and multiple objectives usually require multiple policy instruments. OECD (2021a) suggests, as a rule of thumb, adopting the 'Tinbergen rule' (Tinbergen, 1952), i.e. using *as many instruments as objectives*. Although one policy instrument has positive effects on different objectives, complementary policy actions are thus usually needed to achieve them fully. However, an interesting aspect to consider and eventually exploit is that the amount of effort required to implement the various targeted policies may be reduced if synergies exist between these objectives. Thus, if synergies emerge, the main issue is the 'calibration' of the best combination of policy instruments and the extent to which they must be used, considering empirical evidence on their effectiveness compared to other tools.[15] To assist policymakers in selecting the proper policy instrument and the extent to which it should be used, models that allow the quantification of synergies are crucial. An example of this type of synergy assessment is given by the studies that have estimated the impacts of the imposition of some of the F2F targets on EU agriculture (see, among others: Beckman et al., 2021; Barreiro-Hurle et al., 2021, 2022; Cortignani et al., 2022). Among these, Cortignani and Coderoni (2022) presented an analysis for Italy of the likely effects on agricultural added value and environmental externalities of adopting some environmental targets, as envisaged by the European F2F strategy and EU climate law.[16] The results show that the imposition of these targets produces evident trade-offs between economic and environmental objectives, although highly differentiated across each scenario by farm type and size, but also reveal important synergies among different aspects of performance in meeting environmental targets that should be further scrutinised to assess whether they could be exploited to obtain multiple environmental outcomes.

When trade-offs are found, instead, the first step is to identify possible alternative instruments to use. Often trade-offs (and synergies) depend on the choice of an inappropriate policy instrument, and they tend to be more severe when a single instrument is used to achieve multiple policy objectives.

For example, a common source of trade-off found in many OECD countries is the benefit provided to farmers by fuel tax concessions (which also occur in Italy), or lower VAT rates applied to pesticides and fertilisers (OECD, 2020). In this case, it would be preferable to separate the two policy objectives (income support and the ES) by targeting income support with a different tool and levying a tax on carbon emissions generated with fuel consumption (thus applying the PPP).

If trade-offs still exist after the right policy tool is identified, there is a need for mediation between competing objectives, which inevitably requires value judgments, an approach that runs counter to identification and calibration, which place major emphasis on technical analysis. By allowing participants to reflect on data and arguments as well as their personal views, democratic deliberation could be beneficial (Dryzek and List, 2003). However, if foreign parties are not represented, even such a deliberative method might not be able to resolve transboundary spillovers (see Section 3.3). To conduct such an analysis of the interactions between policy objectives, it is crucial to invest in reliable systems to acquire the best evidence to inform policymaking. However, as these decisions are never made with perfect information, it is important that the uncertainties concerning the potential synergies and trade-offs of different policy options are made explicit.

Figure 1 proposes a schematization of the main PC issues analysed.

3.3. Governance concerns

Governance issues related to PC are very complex when the policy objective, as in this case, involves different policy domains that often belong to different decision centres (e.g. different ministries, departments, agencies), different government levels (e.g. the EU, states, regions, municipal/local governments) and thus different governance structures and time horizons (e.g. medium-term policies like the CAP and long-term strategies like the Green Deal).

In Europe, policies are designed and implemented by the European Multilevel Governance (EMG) system, through which the EU, its member states, and regional

[15] For example, to reduce GHG emission it can be used a tax on consumption of some food products (e.g. red meat) or on the total GHG emitted by the farms, but only using the tax on consumption the double goal of reaching higher ES and health benefits can be reached.

[16] These targets are represented by *i)* the reduction of 20% in chemical fertilizers use; *ii)* the reduction of 50% of more hazardous pesticides; *iii)* the 50% reduction in the expenditure of antimicrobials; *iv*) the previous three targets together and *v*) the reduction of 30% of agricultural GHG emissions.

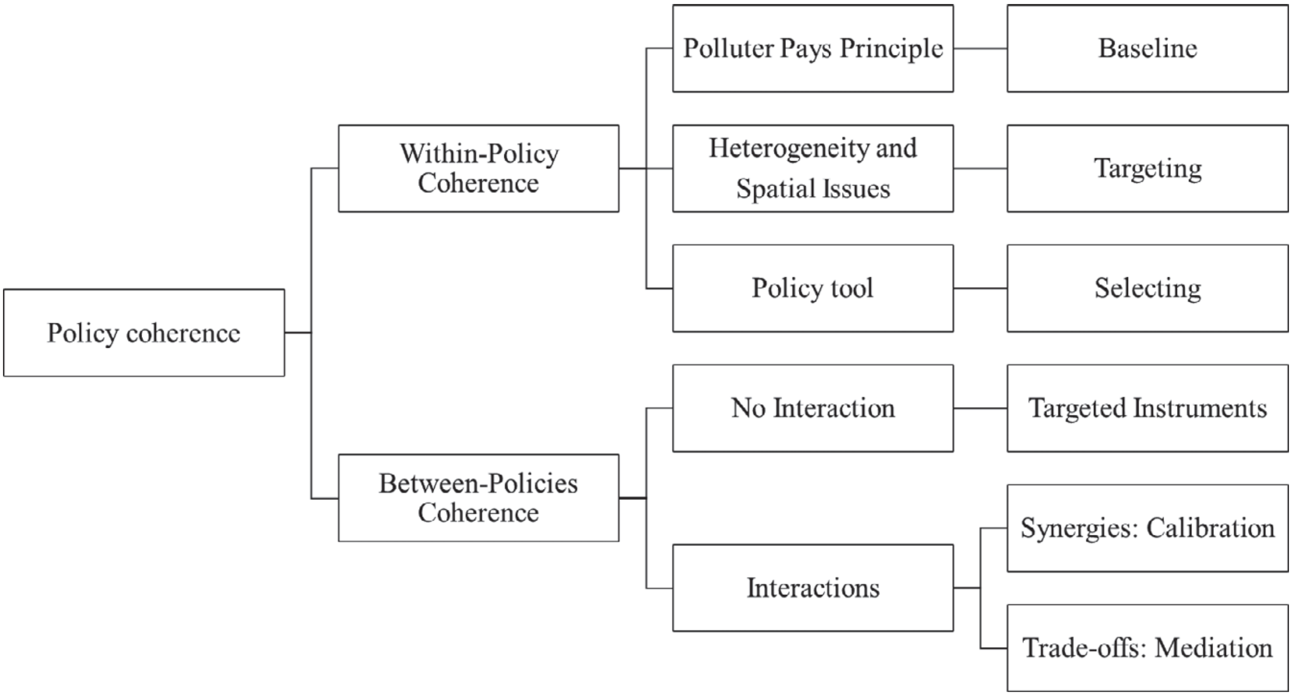

Figure 1. A schematization of the PC issues. Source: Author's elaboration on OECD, 2021a.

and local authorities cooperate at the operational and institutional levels (EU Committee of the Regions, 2013). Being part of this EMG system, decision competencies rest at different levels for the agricultural, environmental, and climate sectors (Venghaus and Hake, 2018). This distribution of decision competences and means can significantly affect policy design in the implementation of FS and ES objectives. The CAP is, in fact, primarily a distributive (of funds) policy which is also highly communitarized, while, for example, biodiversity and water policies are regulative (set rules and standards; Berkhout et al., 2015) policies and, like energy policy, are left primarily to national implementation.

In such a complex governance framework, some level of coordination would be needed between policy communities. To reach PC, this coordination could range from simple collaboration to real forms of 'policy integration' (Parsons, 2019). Starting from Parsons's definition of an integrated food policy, an integrated FS and ES policy would be represented by the joining up of goals and policies related to relative domains – '*horizontally across governments, vertically between government levels, or between inside and outside government actors – to better align these efforts, reduce incoherence between them*' (Parson, 2019: 3), and tackle related challenges more effectively.

PC and integration of the policymaking process are thus not the same concept, and a coordinated approach to policy would require both of them. If PC refers to avoiding conflicts of objectives and results within and between different policy domains, policy integration refers to some form of coordination that can range from simple collaboration on some specific themes to complete functional integration by giving only one decision centre (e.g. a ministry) all responsibilities over a policy area. Although the latter is the easiest way to help institutions align their objectives and policies, this type of policy integration is neither easy nor costless (OECD, 2019b). In fact, in some cases, complete functional integration cannot be reached (e.g. in the case of different territorial levels involved), or it can bring various degrees of risks: higher integration can conflict with principles of decentralisation or of subsidiarity[17] or can increase coordination efforts at the expenses of better programming (Candel, 2017). Thus, ideally, the degree of

[17] Although in principle more subsidiarity would seem to be desirable to achieve higher PC, as it puts forward a better targeting of goals to specific territorial needs, in practice the principle itself could be an obstacle to reach PC for two main reasons. First, environmental and climate objectives are often trans-boundary problems, therefore, national or local action alone are unlikely to lead to best possible solutions and a higher EU coordination is needed. Secondly, although the best way to achieve PC should be a complete functional integration, this is actually not feasible within the EU governance setting. Thus, to apply the subsidiarity principle and attain PC, what is needed is more coordination among the different territorial levels.

coordination between policy communities should match the intensity of synergies and trade-offs between their respective policy domains (OECD, 2021a).

Another obstacle to the governance needed to achieve PC is the transboundary *spillovers* that can characterise agricultural and environmental policies. Domestic policies in these fields can have transboundary effects on one or more countries and even global effects. To the extent that interactions are domestic, the costs and benefits of PC are also domestic. In this context, the transaction costs of achieving PC can be better justified, and choices can be made within the country's decision-making boundaries, simplifying the process of coordinating different policymaking communities and information recovery. When policies have an impact on other countries, instead, PC itself becomes a common-pool resource, with the related problems of under-provision and collective action failures (OECD, 2019a). International stakeholders can rarely advocate their interests in foreign policy-making processes, and the *benevolent social planner* 'fails to operate' at the international level. The case of the global public good given by climate stability offers the most relevant example of such an international case of PC that is tough to tackle.

International collaboration should be put forward in this instance, reconciling domestic goals with the advantages of international cooperation (von Lampe et al., 2016) as collaborative approaches can lead to meet of global challenges by realising mutual gains (OECD, 2021a).

One strategy to cope with complex governance for the PC could be represented by focusing on goals integration, via goal-based governance, by incorporating environmental goals - such as climate change mitigation and biodiversity preservation - into agricultural policies to ensure that they consider these priorities and then put forward goal-based governance. Such an approach, in contrast to 'rules-based governance', sees the engagement of a wide range of stakeholders in recognising shared problems and setting broad objectives (Kanie et al., 2019). The process allows an early consensus on goals, targets, and subsequent indicator definitions (Biermann et al., 2017). After stakeholders are involved, they establish priorities, gather resources, build the institutions needed or modify existing ones, and inspire individuals and institutions to work toward the goals (Kanie et al., 2019). This strategy, indeed, builds on insights gained from researching effective management of common-pool resources, including the necessity of defining users, developing inclusive decision-making processes, and creating rules that are adaptable to local needs (Ostrom, 1999).

At the international level, the Sustainable Development Goals and the Paris Agreement on climate change seem to have adopted this goal-based approach, with '*a shift away from international rule-making towards a system based on goal setting*' (Kanie et al., 2019: 1745), though only the second is legally binding. At the European level, such an approach seems to be put forward by the framework of the reformed 2023–2027 CAP, in which policy-specific objectives are linked to common EU goals for social, environmental, and economic sustainability in agriculture and rural areas (including the F2F ones), and the focus on the results of the policy, with a wide set of indicators to monitor its signs of progress, seem to support – at least on theoretical grounds – the idea of goal-based governance.

In fact, each member state is free to select and further design, in its Strategic Plan, the specific measures it considers the most effective in meeting its own specific needs (European Commission, 2020c).

Although this could result in a lack of harmonization and comparability between member states, as seems to have been the case for the Directive on the Sustainable Use of Pesticide (European Commission, 2017a; 2020d), in theory, the Strategic Plans should put forward a more coherent intervention logic, based on specific goals decided with a higher level of subsidiarity and shared with local stakeholders.

However, according to Lovec et al. (2020)[18], the new CAP will not probably make much of a difference in terms of overall policy effectiveness and coherence. Since the programme logic of the new CAP will be like the past RDPs, the majority of the shortcomings in the existing planning system[19] are likely to continue, and the strategic plans will only assist the Commission in more fairly allocating responsibility to member states. In fact, according to the authors, the new CAP lacks a robust *ex post* policy impact assessment framework, as most of the result indicators proposed are output or short-term outcome indicators, and this will hinder the achievement of substantial improvements in policy effectiveness and make trade-offs between objectives explicit[20] (Lovec et al. 2020).

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[18] The authors propose an interesting ex-ante analysis of the New CAP Delivery Model. As strategic plans for the new period were not available at the time of the analysis, the authors used data from 2015-2020, a period with similar overall policy objectives, measures, and programming principles of the new legislative proposal, for the country analysed (Slovenia).

[19] The European Court of Auditors evaluating the CAP 2014-2020 programming period, argued that interventions target too many objectives that were too general (European Court of Auditors, 2017) and highlighted a weak linkage between the objectives and interventions (European Court of Auditors, 2018).

[20] As demonstrated also by the evaluation of the 2015-2020 RDP system (European Court of Auditors, 2017).

Additionally, policy tools largely remain unchanged, along with current issues of poor targeting which cause poor transparency (Swinnen, 2015). Thus, although the CAP 2023-2027 foresees higher shares of green spending, this does not necessarily imply that environmental objectives will be reached. Indeed, also in the past programming period, as stated by the special report by the European Court of Auditors (2022), although half of all climate spending from the 2014-2020 EU budget related to agriculture, farm emissions had not decreased because of this.

Furthermore, stakeholder involvement commitments seem to be rather weak. At best, the effectiveness of the new delivery model will rely on the goodness and administrative prowess of governance systems within each member state. However, the issue of administrative capacity will be a substantial challenge for many member states that have little experience on programming of Pillar I and also Pillar II measures (Lovec et al., 2020).

4. LIKELY POLICY COHERENCE APPROACHES

In several OECD countries, RIAs are used by policymakers to evaluate PC before developing new regulations (OECD, 2021a). In the EU, the RIA is a foundation of the policy-making process as stated by the EU 'Better regulation for better results' (COM(2015)215) and the subsequent 'Better regulation: Joining forces to make better laws' Communications (COM(2021)219). The guidelines on impact assessment call for a comparison of various policy choices based on their economic, social, and environmental implications, with quantification of impacts, whenever available. In particular, the RIA should include the description of those who will be impacted, how they will be impacted, and any potential effects on competitiveness. Also, impact analyses must include the consultation procedure adopted (European Commission, 2017b).

Indubitably, this approach to the RIA strengthens PC by using an ex ante assessment of potential trade-offs and synergies and enabling a comparison of various policy choices, considering their interaction effects. However, to tackle the ambitious joint target of reaching FS and ES, a more proactive role for policymaking should be foreseen that goes beyond the usual requirements of the RIA. In fact, when dealing with such a complex policy objective, there is no single policy cycle[21] but rather several policy cycles involved, and policy objectives may also contradict each other. Thus, they require a joint analysis, i.e. a coherence assessment.

An approach increasingly used to foster PC is to adopt a more complex multi-stakeholder consultative approach for long-term strategies or policies. An interesting example, in this case, is the 'Collaborative Framework for Food Systems Transformation', established by the One Planet Network's Sustainable Food Systems Programme, a multi-actor partnership focused on accelerating critical transformation towards sustainable food systems (UNEP/SFSP, 2019). The framework recognizes that creating PC for complex, interrelated issues requires cross-sectoral, participatory approaches (ILO, 2021) and acknowledges the importance of involving various levels of governance and analysing synergies and trade-offs between outcome goals, recognizing the importance of EIP across the whole policy cycle (Alliance of Bioversity et al., 2021).

This coherence assessment could be used to not only appraise new policies but also assess the coherence of established policies. An example, in this case, is represented by the G20 fuel subsidy peer review (OECD, 2018), in which countries conducted self-reviews of domestic fossil fuel supports and submitted these self-reviews to a review team. This process has allowed a within-country appraisal of inefficient policies and a rare coordination and dialogue on PC across countries.

Also, different levels of policy integration can be utilized to increase coherence; however, as mentioned, integration has a price and does not always guarantee better results (Candel, 2017).

An RIA can be used to assess the transboundary effects of proposed policies to avoid unnecessary costs, e.g. through the assessment of trade impacts and impacts on foreign jurisdictions. Thus, policymakers can improve global PC with proper policy processes in their domestic regulatory practice, even without explicit coordination, but just with the consultation of external stakeholders or compulsory notification of draft regulations to international fora (OECD, 2021a), like in the case of the World Trade Organization Technical Barriers to Trade and Sanitary and Phytosanitary measures Agreements with the single central government authority responsible for notifications (OECD, 2021b).

Aligning global targets to local contexts should be the norm but can, of course, create challenges in implementation. Goal-based governance could help reach such ambitious policy objectives as long as it implies cross-

[21] From its origins in the 1950s, the field of policy analysis has considered the policy process as evolving through a sequence of discrete stages, defined as the policy cycle. Over the years, several different changes in the stages' typologies have been developed; today, the distinction between agenda-setting, policy formulation, decision-making, implementation, and evaluation is quite commonly accepted (Jann and Wegrich, 2007).

silos interaction, encourages participatory and deliberative methods and adopts 'backcasting' approaches. This basically implies setting time-bound concrete quantified goals and targets, designing a viable pathway to achieve them, 'backcasting' from the future desired state to the current situation, and measuring progress, gradually adjusting the ambition of targets over time (Kanie et al., 2019; Sachs, 2015). These pathways should incorporate the key measures, their costs and financing, and the organization of the implementation strategy, e.g. through public and private investments (Sachs, 2015), aligning all actors from private to public, with inclusive and adaptive decision-making. In this context, better tools for multi-sectoral scenario planning and modelling could help mapping pathways to achieve multiple goals simultaneously (Pascual, 2022).

Setting goals based on what is needed rather than what is immediately feasible will encourage the necessary levels of creativity to attain them, and this will help exponential progress rather than (as is often assumed) linear progress (Kanie et al., 2019). However, if these goals are not shared with the stakeholders, there is a high risk of creating dissatisfaction among some of them and can also limit the application of a PC approach (Bruere et al., 2022), as happened in the case of the F2F strategy targets (Copa/Cogeca, 2021).

Recent research has highlighted the importance of reaching positive tipping points to speed up the transformation of complex systems (Fesenfeld et al., 2022; Van Ginkel et al., 2020). The socio-technical tipping literature suggests that small-scale changes in a system can move sensitive systems into a qualitatively new state due to strongly self-amplifying (net) positive feedback mechanisms (Sharpe and Lenton, 2021; Fesenfeld et al., 2022). Thus, transformative change can occur using leverage points which alter future trajectories (e.g. consumption patterns), and this can help create a climate and biodiversity-resilient development pathway (Pascual, 2022; Pörtner et al., 2021).

Currently, there is a lack of knowledge about the politics of enabling such positive tipping points (Fesenfeld et al., 2022), but hints can be derived from policy feedback literature that could help overcome barriers that impede reaching tipping points (Béland and Schlager, 2019).

5. CONCLUSIONS

FS and ES challenges are joint global problems and must be addressed jointly to be solved (or to make progress towards their solution), as there cannot be FS without ES. Even if short-term shocks can point attention to one objective, in the long term, they are indubitably interlinked. Policymakers should thus pay attention to how to reconcile short-term (often counterproductive) replies with long-term goals.

There is no doubt that implementing such a complex multi-objective policy requires a higher level of PC which, in turn, requires cross-silos, participatory approaches and a backcasting method.

PC should be pursued within policy and between policies. To analyse the *within PC*, the focus here was on the CAP as the primary policy for the EU agricultural sector. The main challenges in including environmental objectives in the CAP are related to applying the PPP, which also requires defining the appropriate baseline, dealing with the heterogeneity of replies and with spatial problems and choosing the proper policy tool. All these arguments call for better targeting and even tailoring of policies that will surely benefit from new instruments offered by digitalisation.

To reach *between PC*, instead, after simplifying the policy framework, an analytical task should be developed aimed at identifying synergies and trade-offs among policy objectives. Where synergies emerge, policymakers should be aware that there are rarely 'silver bullets' and that multiple objectives typically call for different policy instruments that should be properly calibrated using a mainly 'technical' approach. When trade-offs between competing objectives exist, often the solution is changing the adopted policy instrument. If trade-offs persist, value judgements should be made, making domestic and transboundary trade-offs explicit to support shared and open decision-making.

Policy integration is often advocated to reach PC; however, this comes with costs and is not always feasible. Implementing goal-based governance could represent a means to overcome the difficulties of policy integrations and could also help in using leverage tipping points in socio-ecological systems which alter future trajectories towards the changes needed.

Whether or not the EMG system is adequate to sustain such a PC approach remains an open question. What is certain is that the EU agricultural policy has a long history as a European policy, as it represents one of the first policies by which the EU has tested its legislative process and institutions (Sotte, 2022). If the EU agricultural policy meets the complex challenges facing it, it might represent once more the context in which future EU policymaking processes and governance settings are tested.

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Keynote speech of the 11th AIEAA Conference

Towards a new generation of (agri-) food policies

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Abstract. The succession of systemic crises in the last 20 years have affected our lives and have shaken the old order. The global community, represented by UN-based institutions, has encouraged a common effort to address global challenges. In the agri-food sector, one of the most relevant to the emerging societal challenges, the need of a new generation of agri-food policies is evident. The present paper reviews the recent literature on transformative policies, identifying their key characteristics - directionality, reflexivity, and market articulation - and proposing a framework to adapt these characteristics to the policy cycle.

Keywords: transformative food policies, transition, policy cycle, policy mix.
JEL Codes: Q18.

1. INTRODUCTION

The succession of systemic crises in the last 20 years have affected our lives and have shaken the old order, built upon the primacy of economy and trade over social and environmental problems. The global community, represented by UN-based institutions, has encouraged a common effort to address global challenges. Despite all difficulties, and many stops and go, there is now a wide consensus on global challenges, and agreements on climate, biodiversity and sustainable development goals have been embodied into national laws and have been turned into quantified targets and into accountability mechanisms (TAP network, 2021).

International agreements have activated new frameworks for the public debate at national level and generated new dynamics within political and economic communities. In the new context, a growing number of private and public actors commit to sustainability objectives. Pushed by an increasing consumers' sensitiveness, many companies tend to shift the arena of competition on sustainability issues by providing higher standards that allow them to communicate sustainability values (Giovannucci et al., 2014). Policy initiatives encourage European food business to coordinate sustainability standards and their communication and punish greenwashing. Backed by international agreements, the most sensitive sectors of the public administration to sustainability gain power on more conservative administrative bodies and become drivers of change. Research and innovation policies encourage the production of new ideas and the dismissal of old paradigms, selecting research projects on their capacity to have an impact on societal challenges. In the political domain, environmental movements have started to bring governments into Courts[1] claiming that they don't respect their climate obligations.

In the agri-food domain these dynamics are particularly relevant, given the importance of agriculture and food on climate and sustainable development goals. Many influential reports in the last years have agreed on the need to transform the way we eat, produce, distribute food[2]. As the UN general secretary have stated in his Summary and Statement of Action of the Food System Summit of 2021, food systems are contributing up to one-third of greenhouse gas emissions, up to 80 per cent of biodiversity loss and use up to 70 per cent of freshwater, and three billion people — almost half of all humanity — could not afford a healthy diet. The Food System Summit has mobilized tens of thousands of people in food system dialogues aimed at making proposals for food system transformation.

The issue is not whether to change, but how and how fast. One of the problems, on this regard, is that we cannot change the system with the same policy instruments used in different historical contexts (Rogge and Stadler, 2021). A new generation of policies is needed. This paper will try to address this issue by developing a reflection around the following questions: What are the qualities that a new generation of policies should have? What should be done to foster a new generation of policies?

2. THE CHARACTERISTICS OF TRANSFORMATIVE POLICIES

According to a growing number of scholars and practitioners, transformative goals require transformative policies (UNSRID, 2016; Rogge et al., 2020; Giurca et al. 2022, Haddat et al. 2022), that are able to activate processes of structural change by affecting the root causes and the deep structures of the systems on which they operate. The difference between the new generation of policies and the old 'grand reform' approaches is the awareness of the complexity of structural change, the awareness that transformation cannot be imposed in a top-down way and that organic, all-encompassing solutions are hard to succeed. Transformative policies operate into arenas wherein a multiplicity of actors struggle to influence policymaking (Loorbach et al, 2015), and where sectors of the same governments pursue different objectives and operate according to different logics.

Having this in mind, policymaking is not seen as a timeless mechanism where outcomes follow decisions automatically. Rather, policymaking is seen as a process, articulated into phases characterized by different dynamics (Howlett, 2019). In the 'problem definition' phase, knowledge, interests and values are mobilized to 'frame' a policy problem in terms of its causes, outcomes, responsibilities, actors involved. In the 'agenda setting' phase policy problems gain or lose priority in the policymaking agenda. In the 'policy design' phase, policies are deliberated and adopted by institutional bodies. In the 'implementation' phase, policies are applied in the various contexts and deploy their outcomes. Implementation can include also monitoring and evaluation, which provides information on the efficiency and of the effectiveness of policies.

Each of these phases involves different categories of actors and networks, and different expertise. The policy process interacts with the political process, as political actors (parties, movements, members of representative bodies, media) interact with policymakers in all phases.

The impact of policies on socio-technical systems depends on the characteristics of the system: the capacity of its actors to adapt, the robustness of its rules, the vulnerability of its components, the sensitiveness to specific measures, the distribution of power within the system. Feedbacks from socio-technical systems can alter policy decisions and their implementation (Rogge et al., 2020), as when Macron was forced to withdraw its proposal of taxing fuel under the push of the movement of the 'gilets jaunes'.

The policy process can undergo rounds of depoliticisation and repoliticisation (Wiesner, 2021). Depoliticisation occurs when the problem definition is no longer contested, so that policy design is carried out outside the political spotlight and made mainly by experts. Repoliticisation occurs when the effectiveness of the policy, or even the problem definition, is put into discussion. During repoliticization, the agenda setting and policy design are supported or contrasted by competing advocacy coalitions (Mintrom et al., 1996). During depoliticization, policy design and policy implementation are carried out through policy networks, composed by public officers and stakeholders' organizations who share the same assumptions, the same problem definitions, the same objectives.

[1] https://www.unep.org/news-and-stories/story/battle-against-climate-change-courts-become-new-frontier

[2] We could cite among others: the FAO SOFI 2021 (FAO, 2022); Global Panel on Food Systems for Nutrition (2020); IFPRI (2020); SAPEA (2020); Willet et al. (2019), Brunori et al. (2020)

Transformative policies intervene in this process with the goal to remove barriers to change and to support change makers. They also can repoliticize the policy problem providing new evidence and new ideas for problem definition. They can be introduced to activate processes of change within the administration itself and give power to 'institutional entrepreneurs' within the administrations.

Transformative policies differ from other policies for three main aspects: a) values and principles to which they are inspired; b) the knowledge base necessary to manage them; c) the intervention pathways they adopt.

2.1 Values and principles

The transformative potential of policies depends on their capacity to appeal to shared values and principles. The more they are based on consensus, the less they are likely to face open contestation. International agreements such as the Sustainable Development Goals provide plenty of transformative values and principles. But these principles have not prevailed without resistance. They have progressively challenged the market-centered principles embodied into the so-called 'Washington Consensus', that constituted the key assumptions of economic policies in the capitalist world. As Williamson - one of the first to introduce the term - pointed out, the Washington Consensus postulated the primacy of market forces, recommending budget discipline, market liberalization, price stability (Williamson, 2003). Serra and Stiglitz (2008) have provided a radical critique to it, pointing to the fact that this consensus fails to address social and environmental consequences of policies. Birdsall and Fukuyama (2011) have observed that developing countries, after the Asian crisis, have given much more emphasis to social policies rather than on efficiency. Critiques to the Washington Consensus have stressed the relevance of market failures, pointing out that not always markets generate optimal outcomes. After the crisis of 2007, the Obama administration openly contradicted the Washington Consensus introducing an aggressive program of public spending (Rehman, 2010), and opening a new phase of economic policies. The Next Generation EU and the Inflaction Reduction Act of Biden go in the same direction.

The Paris agreement and the Agenda 2030, both of 2015, reflects a radical change in approach. The emerging new consensus around Sustainable Development[3] introduces a hierarchy between ecological, social, and economic goals. The notion of Anthropocene, now at the basis of the concept of sustainability, implies that human activities cannot trespass 'planet boundaries', environmental pressure levels above which human habitats could become less stable and hospitable (Willet et al. 2019). As Kate Raworth (2017) has highlighted, not only biophysical planet boundaries, but also social boundaries should be considered. In her 'doughnut economy', called in this way because it is represented by two concentric circles, Raworth (2017) explains that while the ceiling of a 'safe and just operating space' is given by biophysical constraints, the floor of this space is represented by minimum social standards: not respecting them put stability of human systems at risk. These metaphors raise the questions: are policies we are designing keeping the planet within the operating space? Do they improve the desired outcomes without creating harms to other outcomes? In this approach, market forces are considered in a much more pragmatic way, while public policies as well as civil society get more weight in the definition of policies.

After Trump, the COVID and in the middle of the Ukrainian crisis, the Sustainable Development consensus looks much weaker than in 2015. The international order looks in transition from a bipolar to something different, maybe a multipolar world. War and tensions between superpowers have weakened the authority of international institutions. Common global trade rules are undermined by protectionist policies. Globalisation turns into regional economic spheres of influence. Public deficit spending aimed at coping with the multiple crises has generated inflation and debt. In the meanwhile, last summer droughts and the intensification of extreme meteorological events show that the climate crisis is still there. The tension between those who think that the crisis shows that the urgency of the transition is even more necessary and those who want to rethink it is more and more evident. For Europe, keeping a strong emphasis on Sustainable Development Goals is a way to gain a leadership based on principles universally recognized rather than on force. So far, the roadmap established by the Green Deal strategy is proceeding fast: the main concern is related to the capacity to Member States to follow. Here is the role of transformative policies.

2.2 Knowledge base

Transformative policies require a new knowledge base (Clark and Dickson, 2003). In the economic field, most of the concepts emerging in the sustainability debate are generated outside the old economic toolbox and make pressure on economists to open their studies

[3] For an illustration of the term 'consensus framework' with reference to food security, see Mooney e Hunt, 2009.

to other fields of knowledge. Economists are encouraged to abandon mechanical system approaches in favor of complexity and to consider (positive and negative) feedbacks, emergent properties, unintended consequences of choice, and trade-offs related to different perceptions of agents (Arthur, 2021). Attention to complexity brings to consider the hybridity of the systemic connections: the notion of socio-technical systems (Geels, 2004) captures the interplay between social and technological domains, and the notion of 'socio-ecological systems' (Anderies et al., 2004) looks at how human activities generate wellbeing as well as pressure on natural resources. System approaches are inductive - that is, they start from empirical evidence to build theory - and the empirical work is finalized to build representations of systems around specific problems (Gharajedaghi, 2011), so to produce knowledge immediately useful for practical purposes.

System approaches are aware that different sets of actors can develop multiple representations of systems, none of them intrinsically 'true' or 'false', and that actors behave according to their representations of the system. This principle applies also to science-based representations, the differences between which depends on their conceptual assumptions and their systems of values (Bené et al. 2021). This also opens the way to a new generation of quantitative models, such as agent-based models (LeBaron and Winker, 2008) and system dynamics (Uriona and Grobbelaar, 2019). Applied to policies, this approach emphasizes that policymakers deal with a multiplicity of system representations based on different actors' perspectives and values, and their task is to broker between different representations. For example, reading food systems with the lens of food security is different from reading it with the lens of competitiveness, and seeing food as a commodity might convey a representation of the system much different than in case of considering food a human right (SAPEA, 2020). Stakeholders' participation in building representations of the systems is thus necessary to the success of transformation policies. For example, concepts such as the food environment, central in the debate on sustainable food systems, have a strong subjective component, related to the time-space patterns of daily lives (Mattioni et al. 2020). Citizens' involvement on food system appraisal can open researchers' eyes on otherwise neglected aspects.

Policymaking, rather than being considered external to socio-technical systems, is increasingly considered as an endogenous variable (Smith and Stirling, 2007), affecting and being affected by system actors and activities.

Once emancipated from market failure approaches and exposed to other knowledge domains, the thought in this field has undertaken research pathways based on systemic concepts such as food environment, food-resources nexus, resilience, circularity, ecosystem services (Galli et al. 2020).

A stronger attention to societal challenges also has implied a greater attention to 'actionability' of knowledge produced by research (Kirckoff et al. 2013), meaning that research should provide responses to problems that fit to users' needs. Obsolete approaches to scientific research tend to separate scientists from the rest of society and to create a unidirectional flow of information from research to practice. In the new approach, engagement of researchers with policymakers and stakeholders in all phases of research is necessary to build a common language and a shared representation of the systems observed. Interaction helps to develop a shared understanding of problems, needs, barriers to solutions. This implies acknowledging the complementarity of different types of knowledge and the need to find different criteria for knowledge validation (Cundill et al., 2015; Jacobi et al. 2022).

2.3 Intervention pathways

In a post-Washington consensus, market forces can even become barriers to transformation or drivers of degradation. When market loses its primacy, State and Civil Society gain a stronger role. Mazzucato (2013) proposes an entrepreneurial State, taking the example of the Apollo program which brought humans on the moon. More in general, it is said that sustainability cannot be achieved without transitions, and that management of transitions implies managing structural change (Loorback, 2007). According to Weber and Rohracker (2012) system approaches search for solutions to problems by shaping differently the patterns of interaction in a system (Ericksen et al., 2012; Haladi, Rao, 2010). The growing literature on transitions shows that transformative policies must have three properties: directionality (that is, goals of change defined in the public sphere), reflexivity (that is, capacity to learn from experience), market articulation (that is, influencing the way markets are shaped) (Grillitsch et al., 2019).

Directionality implies building visions, establishing long term goals, setting pathways (Weber and Rorhacker, 2012). For this reason, consensus frameworks are important, as they support legitimacy of policy directions. Policies based on directionality principles make use of strategic tools: they tend to facilitate rather than prescribe, have a contractual basis, and rely upon the autonomy of social forces. Figure 1 represents three pathways for policy processes: one initiated by civil society, one by business, and the third by government

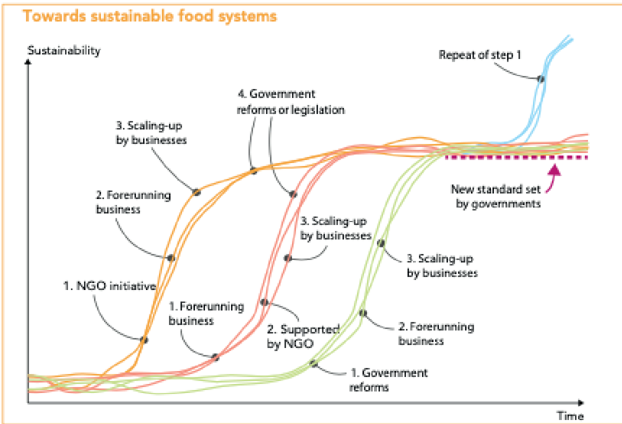

Figure 1. Transformation pathways (Source: UNEP, 2016).

reforms (UNEP, 2016). In the first and the second pathways the State intervenes with regulation when the conditions are already ripe, after that NGO initiatives and business have opened the way. Organic farming can be considered an example of the second pathway, as the European Regulation came after a bottom-up process of innovation carried out by forerunning business backed by NGOs. Palm oil-related initiatives have been started by NGOs mobilization and have been incorporated into business practices (Oosterveer, 2016). In a complex policy system as the European one, where there are multiple level of governance, local administrations or forerunning Member States can play this initiating role. Soft law, as in the case of voluntary standards or the EU code of conduct on responsible food business and marketing practices[4], can activate societal and business energies and prepare the terrain for hard law.

Directionality also implies active efforts to pursue coherence between policies. For example, it has been observed that policies aimed at reducing carbon emissions might create pressures on biodiversity, and that policies supporting biofuel could put food security at risk (Standish et al. 2020), not to speak of the compatibility between the new CAP and the Green Deal (Guyomard et al., 2020). However, hardly coherence can be addressed with fully coherent, all-encompassing policy design. As van Bers et al. (2016) point out, barriers to change can be related to lack of access to resources, effectiveness of formal institutions, lock-in to a reigning paradigm. For de Jesus and Mendonca (2018), barriers can be classified into 'hard' (technological and financial) and 'soft' (institutional and cultural). In a concept of policy as a process, there is a need for actors, networks and institutions ('institutional entrepreneurs') that foster coherence with the general objectives, and policies that support them removing barriers to change. The presence of enablers and barriers to transformation make us also aware of the need to address the problems with policy mixes rather than with single, and separated, policy measures (Rogge et al., 2020).

The second property, reflexivity, is based on the awareness that governing the transformation implies managing uncertainties, systemic trade-offs, cross-sectoral interactions, power dynamics and conflicting perspectives (European Commission, 2021). This implies that the policy process would be better based on experiment, learning, and adaptation. In the transformative intervention logic, innovation is at the center of policies, as a catalyst for transformation (de Boer et al., 2021). Innovation can contribute to address trade-offs (for example, between economic and environmental outcomes) by providing win-win solutions. Given the open nature of transformation processes, bottom-up innovation is encouraged to provide insights on levers and barriers to change. Examples of these policies already exist in the European landscape: in the second pillar of CAP, Operational Groups are conceived of as living laboratories for innovation, and the EIP partnership provides a space for comparison, sharing and reflection. Potentially, many rural development measures might have the character of experimentation, provided that they are framed into mechanisms that foster learning. When reflexivity is understood as a key property of policies for transformation, effective governance mechanisms should be developed to ensure that bottom-up innovation activates policy learning. Innovation, in fact, regards also policies: given the complexity of the processes, hardly transformation can be made without learning from policy experiments at lower scale (Mytelka and Smith, 2002).

Given its transformative power, it is important to point out that innovation has not only a technological dimension: social and institutional innovation can play an equal or even greater role. And in any case, it is increasingly recognized that technical, social, and economic domains are not separated from each other, as they operate upon socio-technical and socio-ecological systems. When they challenge the basic assumptions and the principles on which systems operate, all types of innovation concur to system innovation (OECD, 2015).

The third property, market articulation, rests on the fact that market are powerful mechanisms that contribute to orient actors' behavior. When in conflict with actors' economic interests, policies are much harder to succeed. Agricultural economics has long been associated with policy-based orientation, involving actions on supply (such as quotas, price support, or standards)

[4] https://food.ec.europa.eu/system/files/2021-06/f2f_sfpd_coc_final_en.pdf

or on demand (through taxation). However, perceiving markets as context-specific systems of rules and resources that influence actors' behavior allows for significant progress. This understanding helps us grasp how policies can shape actors' choice environment, making them more conducive to change. In the realm of food, there exists a vast body of literature on social innovation, specifically targeting the transformation of market behavior among actors (Chiffoleau and Loconto, 2018). Farmers' markets and purchasing groups, for instance, defy conventional market forces and establish novel market institutions. Voluntary schemes, such as organic farming and geographical indications, create market spaces for innovative products in their introduction phase (Giovannucci et al. 2014). Public procurement is now considered a key strategic policy tool for dietary change, especially when considering specific population groups such as primary school students (Neto and Gama Caldas, 2018). Public procurement can also open markets to innovative products. Nutrition or sustainability labelling aim at orienting consumer preferences (Brown et al. 2020: the debate on nutriscore vs nutrinform in Europe shows how economic interests can be affected by information.

3. POLICY MIXES FOR TRANSFORMATION

The new generation of policies should be evaluated for their capacity to remove the barriers to transformation and to create synergies between agents of change. Important barriers to transformation are often linked to the way administration bodies are articulated, which also affect the way knowledge is produced. Alternative problem framings, mentioned earlier, can reflect separation between different bodies of knowledge.

A clear understanding of the policy process, of the drivers, the barriers, the relevant actors and their relative power is the key to transformative policies, which are based on policy mixes rather than single solutions. Policy analysis should start from a sound assessment of the policy process before identifying solutions. Table 1 illustrates a tentative toolbox for transformative policies in the agri-food domain, articulated into the different steps of the policy process.

Table 1. Transformative policies and the policy cycle.

problem definition	agenda setting	design	implementation
Transformation fora	Roadmaps for transition	Supply-side and demand-side Win-win solutions	Information systems Accountability Addressing resistance Formative evaluation
Transformative governance			

3.1 Problem definition

Transformation implies a redefinition of existing policy problems and the emergence of new ones. Problem definition is highly politically sensitive, so transformation management requires a careful management of stakeholders' involvement. Transformation fora gather stakeholders and administrations to deliberate around specific goals. For example, Policy Labs activated with the Fit4food2030 project[5] are participatory and experimental spaces that bring stakeholders together in a series of meetings with dedicated themes and methods. Policy Labs build a network of diverse stakeholders from different parts of the food system. Together, the stakeholders analyse the current food system and related R&I system in their country or region, identify barriers and opportunities and work on innovating R&I policies. In the aftermaths of EXPO2015, hundreds of municipalities have activated food policy fora to address problems such as nutrition, food quality, relocalization of food systems (Lever et al. 2019). Food communities and Rural Districts, introduced in the Italian legislation, could have the same role in redefining rural needs.

Transformative policies imply decisions on issues the knowledge about which is uncertain and contested, also within the scientific community. Controversies on GMOs, pesticides, the impact of livestock on the environment have animated the policy debate in the last decade. For this reason, a specific attention should be given to the role of scientists. In a context of 'consensus frameworks' such as the sustainability development goals, scientists are supposed to support the process of consolidation or the adaptation of the frameworks through ideas and evidence (Duncan et al., 2022). While on one side they need to resist to capture by policymakers willing to legitimate their decisions, hardly scientists can claim a neutrality between opposing knowledge claims. On the other hand, not necessarily personal convictions should be separated from scientific judgement, as neutrality is not synonym of objectivity, a key ethical principle for scientists. Transformative policies imply commitment to change, and this can give scientists, depending on the context where they operate, the role of 'advocates for change' (that is, look for alliances for change based on scientific evidence) or 'honest brokers' (who make a synthesis of different and

[5] https://fit4food2030.eu/policy-labs/

sometime opposing position and provide ranges of solutions and related implications) (Pielke, 2012).

3.2 Agenda setting

In the agenda setting phase priorities are established. In complex political systems, transformational goals are embodied into the agenda setting process through policy roadmaps. Roadmaps are strategic tools that serve to involve and to align the multiplicity of actors involved in the transformation. They need to be flexible enough to adapt to the conditions of the context, and at the same time they should be capable to mobilize the actors, commit and make them accountable. Policy roadmaps should be based on a clear understanding of the dynamics of the systems on which policies should intervene, of the forces that support the change and those who oppose. The choice of policy instruments and the sequence of the steps to be taken should be based on an analysis of the leverage points, the barriers, the potential consequences of specific choices, stressing the consequentiality of the measures to be taken and their graduality. The need to overcome barriers to change would encourage the search of win-win solutions, and if not possible, participation would identify the groups that could be damaged and the size of the costs they would suffer, so to establish fair compensations.

The Green Deal provide the most relevant example of roadmap, as it defines the goals and desired outcomes related to food, and lists the major steps needed to reach them. A roadmapping approach is implicit in the performance-based approach to the CAP, as achieving specified targets would imply the identification of the steps necessary for transformation and a constant monitoring of the progress.

3.3 Policy design

In the design phase, the complexity of food systems requires an approach to system innovation based on policy mixes, able to address the root causes of the policy problems, mobilize all relevant actors, aim at a variety of objectives. Traditionally, CAP has intervened mainly on the supply side, while much less attempts have been made to address demand. The Green Deal and the Farm to Fork mention the need on acting on the demand side to pursue healthier diets, for example through public procurement, labelling, and education. The project Fit-4Food2030[6] has developed a dataset with 460 policy tools, clustered into six goals: Innovation, Equitable outcomes and conditions, Viable and socially balanced agrifood business, Reduced environmental impacts, Food safety, Balanced and sufficient diets for all. The datasets also classify the tools according to the type of instrument, such as Regulation, R&I, Information, Standards, Labelling measures, Border measures[7].

As the transformation has the power to change substantially the relations of power in the system and the distribution of costs and benefits, policy mixes should also look for win-win solutions, such as compensation schemes for the losers and incentives for the transition.

3.4 Implementation

In the implementation side, the capacity to distribute responsibilities across the system will be crucial. Rather than models based on central administration exerting its disciplinary power upon the actors, contractual models are being developed, based on agreed objectives, clear performance indicators and monitoring of results, which implies accountability of the beneficiaries. The CAP has introduced this new model, but its implementation won't be easy, given the number of actors involved and the complexity of the issues. Measures such as the new eco-schemes or the environmental and climate commitments under the 'second pillar' will need relevant monitoring and control activities to deploy their effects. 'Carbon farming', for example, still raise questions about their effectiveness and their costs (Dumbrell et al. 2016). Digitalization of administrative procedures and effective information systems could reduce transaction costs and improve communication between business, administrations, and civil society (Ehlers et al., 2021). Important steps ahead in the process of sharing Integrated Administration and Control System (IACS) data are made, but the process is slowed down by the reluctancy of Member States to share their data given the concern that more transparency could mean more sanctions (OECD, 2019). In this stage, ideally policy evaluation is a key resource for learning. However, different evaluation models can have different transformational potential. While evaluation of results, linked to payments, can help to structure the principal-agent relationship and provide information in the wider public space, formative evaluation[8] could provide feedback

[6] https://fit4food2030.eu/policy-labs/

[7] https://knowledgehub.fit4food2030.eu/wp-content/uploads/2020/08/FIT4FOOD2030_T2.2-extra_Policy-Cards_190316.pdf

[8] A formative approach to policy evaluation is " astyle of evaluation which is conducted with the participation of stakeholders with the main purpose of improving the definition and implementation of the interventions being evaluated" (Molas-Gallart, 2021)

information to stakeholders to improve their processes, to understand trade-offs, and to learn from failures.

3.5 Transformative governance

Given the importance of the dynamics of the policy cycle in the success or failure of policies, the issue of governance is gaining more and more prominence. Transformative policies imply first of all governance management: as Hoppe (1988) points out, policy problems and governance are the two coins of the same medal, because the way policies are problematized, designed and implemented depend on the actors, networks, and institutions that are involved in the process. Given that drivers and barriers are embodied into actors and networks, the best way to activate processes of change is involving them. The choice of who is involved, in which stage of the process, for what decisions, and the instruments to encourage interaction, is key to effective policies. The design of food policies, for example, requires a big effort to involve actors and administrations belonging to a large variety of areas.

Depending on their composition, governance arrangements can give different weight to the potential outcomes. Bringing together stakeholders belonging to different phases of the supply chain might bring to new problem framings. Involving stakeholders that in general are not involved in policymaking might provide transformative outcomes. Governance can also affect the weight given to different drivers into decisions, as each stakeholder brings different values, knowledge, and interests. Likewise, governance influences the activities and the actors that policy making takes into consideration.

The governance arrangements that have accompanied the Green Deal and the Farm to Fork at EU Commission level are significant. Given that the strategy affects many directorates, the implementation of the strategy has been assigned to a dedicated unit under the Executive vice-presidency of the European Commission, with the power to coordinate the other directorates. Another example of potentially transformative governance is the blossoming of urban food strategies after the Expo 2015, which shows the intention of municipalities to become key actors of food policies and to generate a bottom-up change.

4. CONCLUDING REMARKS

In this paper we claim that a new generation of policies is needed. These new policies are based on system approaches, are conceived of as mixes of different policy tools concurring to given objectives, are aware of the policy cycle and therefore of the distance between expected and real impact.

One of the limits of these policies is related to the fact that they need time. As participation and deliberation are key principles for their success, there is the risk that the rapidity of change and the succession of crises could outprecede decisions or make them ineffective, as the long process of construction of the new CAP has demonstrated. More experience on how to design and implement these policies might speed up the process.

Given that research on transformative policies is at its infancy, there is a strong need for research on these themes, to open the way to a new generation of agri-food policy studies, that reflect on the assumptions and on the methodological bases of agri-food studies. We have observed that the notion of transformative policies implies an attention to socio-technical and institutional mechanisms that regulate food systems. A system approach blurs the boundaries between agriculture, food, natural resources, nutrition, and health, and takes into consideration multicausality, unintended consequences, nonlinear processes. Stronger interdisciplinary approaches are needed, first of all with social and policy sciences. An emphasis on the role of policy actors as agents of transformation would shift the attention to agent-based models. The adoption of the concept of policy process, its articulation into policy stages, and the understanding of the feedbacks that policies receive from socio-technical systems, can help scholars to better understand the impact of policies on society, and to design effective evaluation methodologies.

From the methodological point of view, policy-related research implies a more intense dialogue with policymakers and stakeholders, participatory rather than extractive data collection, co-design of research questions, and continuous feedback on research outputs. This should reduce the distance between scientific outputs and policy outputs and contribute to reduce the time from problem framing to policy implementation.

A new generation of policies implies a new generation of researchers. A new model of collaboration between policy-makers and researchers should begin to experiment with new policy practices for transformation.

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Earliness, phenological phases and yield-temperature relationships: evidence from durum wheat in Italy

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Abstract. The impacts of extreme weather events on crop production are largely heterogeneous along the timing dimension of the shocks, and the varieties being affected. We investigate the yield-temperature relationships for three categories of earliness of durum wheat: early-maturing, middle-maturing, and late-maturing. We disentangle the time dimension distinguishing five phenological stages, as identified by the Growing Degree Days approach. Our panel regression models show that the starting, growing, and anthesis stages are sensitive to changes in minimum temperatures, regardless of wheat earliness. Raises in maximum temperatures during the starting stage are associated with increases in yields until a certain threshold above of which decrease; the opposite is true for increases in maximum temperatures in the maturity stage for late-maturing varieties, and in the end stage for early-maturing varieties. Results imply that farmers and policymakers may adopt ex-ante and ex-post risk management strategies, i.e., choice of variety to avoid severe yield losses and incentives to crop insurance uptake, respectively.

Keywords: climate change, crop insurance, growing degree days, risk management, weather index.
JEL codes: G22, Q18, .

INTRODUCTION

The climate variability and the increased frequency of extreme weather events threaten the agricultural sector (Auci et al., 2021). The simulations on projected yields under climate change conditions show losses in crop production (Challinor et al., 2014). In turn, these, may impact the market dynamics with price increases and changes in firms' profitability margins (Stevanovic et al., 2016). The risk management interventions subsidised by the Common Agricultural Policy (CAP) of European Union (EU), e.g., crop insurances, mutual funds, may help farmers to cope with the potential losses due to climatic changes (Severini et al., 2016; Meuwissen et al., 2018; Shirsath et al., 2019; Giampietri et al., 2020; Cordier and Santeramo, 2020; Rippo and Cerroni, 2022), even better if combined with other ex-ante practices, e.g., agroecological strategies (Altieri et al., 2015). The weather-index insurances (WIIs) emerged as promising tools to indemnify farmers affected by weather damages (Anghileri et al., 2022). The working principle of the WIIs is a compensation based on a proxy (the weather index) correlated with potential yield losses (Abdi et al., 2022). The WIIs may contribute solving the market failures due to moral hazard and adverse selection issues, which are common in traditional indemnity insurance (Santeramo, 2019; Bucheli et al., 2022). The main threat to the well-functioning WIIs relies on the possible low correlation between triggered pay-outs and the occurrence of loss events, a peculiarity referred to as 'basis risk' (Cesarini et al., 2021). The basis risk may assume multiple forms. The temporal basis risk may result from the discrepancy between the timing of the weather index fails and the evolution of the crop growth stages (Masiza et al., 2022). The phenology information collected in publicly available datasets (e.g., through satellite remote sensors) may help reduce the temporal basis risk (Dalhaus et al., 2018; Afshar et al., 2021). Indeed, the phenological stages show different susceptibilities to the weather conditions, a relevant aspect for the weather index definition. As for durum wheat, the timing of the undesired weather events matter. For instance, low temperatures are detrimental in all stages of growth, but the most severe negative impacts are observed during the reproductive stage (Barlow et al., 2015). High temperatures severely compromise the physiological processes during the flowering and grain filling stages (Rezaei et al., 2015; Makinen et al., 2018, Gagliardi et al., 2020). As a matter of fact, taking into consideration the phenological stages within which the weather event occur is crucial to understand the weather-yields relationships better: this concept directly translates into better modelling of the temporal basis risk. Although remote sensing imagery represents a promising technique for identifying phenological stages, many factors, such as the atmospheric conditions (e.g., clouds) or the biotic and abiotic environmental perturbations, may also be relevant to analyse the physiological process (Zeng et al., 2020), but are complex in nature and computation. On the other hand, a fixed calendar approach may be oversimplistic and misleading. A second-best solution is to use the Growing Degree Days (GDD), adopted to schedule management activities. It represents a suitable method to predict specific crop stages based on the amount of daily temperature degree (Miller et al., 2001). Conradt et al., 2015 showed that the GDD approach accurately identifies the phenological phases. However, the timing of the phenological stages is not homogenous across varieties. Apart from the studies just mentioned, the literature on the role of varieties in shaping the relationships between yield and weather is quite limited. Thus, departing from a vast literature on the yield-weather nexus (Di Falco et al., 2012; Powell and Reinhard, 2016; Delerce et al., 2016; Chavas et al., 2019), we deepen on the heterogeneities that the yield-temperatures relationship may show across different phenological stages and earliness of durum wheat, hereafter defined as early-maturing, middle-maturing, and late-maturing. Building up the works of Tappi et al. (2022), who show the need to collect more refined data to investigate the relationships between yields and weather variables, and of Tappi et al. (2022), who focus on the role of temporal and design approaches in yield-weather assessment, the aim of our paper is to assess whether the relationships yield-temperature control for three categories of durum wheat earliness (i.e., early-maturing, middle-maturing, and late-maturing) among five phenological stages identified by the GDD approach, focusing on the most representative Italian provinces in terms of durum wheat production. Apart from the new knowledge, our paper has direct implications for farmers aiming to adopt ex-ante risk management strategies (e.g., choice of variety) and for policymakers planning ex-post risk management strategies (e.g., incentives to crop insurance uptake). The Italian participation level in crop insurance schemes is still low, limited to few products, and concentrated in few areas (Santeramo, 2018, 2019; Coletta et al., 2018). Therefore, the focus on the yield-temperature relationship may directly speak with the ongoing debate on how to improve the attractiveness of innovative insurances in a more and more warming climate change scenario.

DATA AND METHODOLOGY

Durum wheat is the main crop in the Mediterranean area for making pasta, couscous, semolina, and other products (Carucci et al., 2020). We collected yields and weather data from 2006 to 2020 of 30 main durum wheat-producing Italian provinces, located in Central and Southern Italy (Figure 1, in the Appendix). Specifically, yearly durum wheat yield data (quintals of production/cultivated hectares) have been collected from the National Institute of Statistics (ISTAT). In contrast, daily weather data have been collected from JRC - Agri4Cast

Table 1. Descriptive statistics of daily temperatures and yearly yield variables from 2006 to 2020 among 30 main durum-wheat producing Italian provinces.

Variable (unit)	Obs.	Mean	Median	St. dev	Min	Max
Maximum temperature (°C)	68,832	13.55749	13.63	4.59804	-5.336364	32.98
Minimum temperature (°C)	68,832	5.899284	6.07	3.919422	-11.65	19.95
Yield (q/ha)	68,299	36.81634	33	12.98301	17	81.42377

Meteorological database of European Commission that includes maximum temperatures (°C) and minimum temperatures (°C).

Descriptive statistics of the dataset are shown in Table 1. More specifically, maximum temperatures show a mean value of 13.5 °C, a median value of 13.6 °C, in a range between -5.3 °C and 33 °C; minimum temperatures show a mean value of 5.9 °C, a median value of 6.1 °C, in a range between -11.6 °C and 19.9 °C,

Furthermore, maximum temperatures exceed 30 °C in some Southern provinces, e.g., Agrigento, Caltanissetta, Catania, Enna, Matera, Palermo, Trapani, while minimum temperatures exceed -2 °C in some Northern provinces, e.g., Bologna, Ferrara, Perugia, Pisa, Ravenna, Rovigo, Siena (Table 2, in the Appendix). We selected weather variables within the timeframe of the wheat production cycle. Several approaches are available to assess econometrically the weather impacts on society and the economy: cross-sections, linear and non-linear panel, long-differences, and partitioning variation (Hsiang, 2016; Kolstad and Moore, 2020). Cross-sectional and panel regression analyses are the most used to assess the climate impacts on agriculture (Carter et al., 2018). Generally, panel model approach uses crop yields as the output of production function, while the cross-section uses a proxy for land productivity, e.g., revenue or profit (Blanc and Schlenker, 2020). According to Hsiang (2016), climate may affect social outcomes in two ways: directly, i.e., the effects of weather in a certain time, and indirectly (i.e., belief effect), i.e., the consequent effects of weather on decisions and actions also referred to as adaptation. Belief effects and other unobservable variables may cause bias in estimates (Hsiang, 2016). In this complex scenario and considering the trade-off among econometrics models, the panel approach presents some advantages for controlling unobserved omitted variables, removing a possible source of bias (Hsiang, 2016; Kolstad and Moore, 2020). Moreover, nonlinear panel models with fixed effects may capture partially long-run adaptive response to climate change (Carter et al., 2018), also contributing to overcoming the main limitations of panel regression: the short-run response to weather fluctuations (Kolstad and Moore, 2020). Therefore, our yield response equation is based on a non-linear panel regression:

$$y_{it} = f(w_{it};\boldsymbol{\beta}) + \alpha_i + \alpha_t + \varepsilon_{it} \tag{1}$$

where y_{it} represents the vector of durum wheat yield data for the 30 main Italian provinces (i) in terms of production volumes and time horizon covered (t). The function $f(w_{it};\beta)$ is explained in the formula (2) below. The estimated coefficients (in bold) are collected in the matrix of first and second-order coefficients noted as $\boldsymbol{\beta}$, whereas α_i and α_t are the vectors of the location-specific and year-specific fixed effects, controlling for unobserved heterogeneity over space and time. The error term is noted by the ε_{it} (Hsiang, 2016; Tack et al., 2015; Kolstad and Moore, 2020). Five phenological stages of durum wheat have been identified through the GDD approach, starting from the sowing date in the middle of November for wheat crop cultivated in the Mediterranean area (Miller et al., 2001): (i) starting, from emergence to two leaves unfolded; (ii) growing, from the end of two leaves unfolded to the beginning of anthesis (first anthers are visible); (iii) anthesis, from the beginning of anthesis to beginning of seed fill; (iv) maturity, from the beginning of seed fill to dough stage; (v) end, from dough stage to full maturity. The GDD approach predicts plants stages from seeding to maturity using the accumulation of heat or temperature units above a threshold or base temperature below which no growth occurs (Miller et al., 2001). The function $f(w_{it};\beta)$ is explicated as follows:

$$f(w_{it};\beta) = \sum_{x=1}^{2}\sum_{s=1}^{s=5}\beta_{xs}{}^{x}\, tmin_{it}{}^{x} + \\ + \sum_{x=1}^{2}\sum_{s=1}^{s=5}\beta_{xs}{}^{x}\, tmax_{it}{}^{x} \tag{2}$$ [1]

[1] We focused on how the temperatures may affect the yields, considering the precipitations as control factor mainly because its effect on yields is difficult to catch (being affected by other variables such as soil texture, management practices, irrigation, etc.). A single rain event may impact on a smaller portion of territory than changes in temperatures affecting entire areas. Therefore, the evaluation of the effect of precipitation on the yields needs of further investigation. Moreover, we controlled for the market shocks, i.e., on how unfavourable years in terms of durum wheat price. The results are robust.

Table 3. Dates of occurrence and GDD values of durum wheat among phenological stages.

	starting		growing		anthesis		maturity		end	
	start	end	start	end	start	end	start	end	start	end
Early-maturing	Nov, 15	Dec, 1	Dec, 2	Mar, 29	Mar, 30	Apr, 19	Apr, 20	May, 16	May, 17	May, 22
(GDD)	(0)	(168)	(169)	(806)	(807)	(1067)	(1068)	(1433)	(1434)	(1538)
Middle-maturing	Nov, 15	Dec, 5	Dec, 6	Apr, 1	Apr, 2	Apr, 22	Apr, 23	May, 20	May, 21	May, 26
(GDD)	(0)	(188)	(189)	(853)	(854)	(1120)	(1121)	(1494)	(1495)	(1602)
Late-maturing	Nov, 15	Dec, 8	Dec, 9	Apr, 5	Apr, 6	Apr, 25	Apr, 26	May, 23	May, 24	May, 30
(GDD)	(0)	(207)	(208)	(900)	(901)	(1173)	(1174)	(1555)	(1556)	(1665)

Note: Referred to the year 2020.

where $tmin_{it}$ and $tmax_{it}$, are the daily minimum and maximum temperatures across space (*i*) and time (*t*). The index *s* ($s = \{1,2,3,4,5\}$) indicates the phenological stage of durum wheat. The apex *x* indicates the linearity of the term. Furthermore, based on phenology calculation combined with the Universal Growth Staging Scale reported in Miller et al. (2001) for the wheat crop, we identified three categories of earliness, i.e., early-maturing, middle-maturing, and late-maturing, also identifying the dates of occurrence of phenological stages (Table 3).

We assume that the sowing date is the same for all varieties (i.e., November 15[2]), although it represents a limit of our paper. However, it is useful to assess yield-temperature relationships among different earliness identified by GDD approach. Instead, the daily thermal sum that determines the transition from one phenological phase to the next, changes. It is interesting to highlight that the shift between early-maturing and late-maturing varieties is just one week. This aspect may play a decisive role in assessing of the yield-temperature relationship and, hence, both on farmers decisions (e.g., choice of earliness) and policymakers to plan risk management policies.

RESULTS AND DISCUSSION

Results display a strong relationship between durum wheat yields and temperatures among different earliness, focusing on the each phenological phase (Table 4, more details in the Table 7, in the Appendix). More specifically, minimum temperatures that occur in the starting phase negatively affect the yields in a non-linear way, until 8-9 °C for all categories of earliness, while maximum temperatures seem to have a positive effect, until 14-15 °C, above of which the yield decrease (table 4 and table 5; more details in the table 7, in the Appendix). Yield is negatively impacted by minimum temperatures linearly occurring in growing stage (table 4, more details in the table 7, in the Appendix). According to the scientific literature, 85% of worldwide wheat cultivation is yearly affected by spring frost causing severe yield losses due to damage of micro-organelles of the cells, excessive production of reactive oxygen species (ROS) and lipid peroxidation (Hassan et al., 2021). Moreover, low temperatures in the fall season may cause yield losses until 9 percent (Tack et al., 2015). Makinen et al. (2018) found that damages due to frost negatively affect all phenological stages, even more the reproductive phase (i.e., flowering). However, focusing on the anthesis stage, our results showed contradictory evidence: minimum temperatures seem to positively affect the yields in a non-linear way, although turning points of temperatures showed that the positive relationship is true until 7-9 °C for all varieties, above of which yields decrease (table 4 and table 5; more details in the table 7, in the Appendix). It is still interesting to highlight that the effect of minimum temperatures on yields is not affected by earliness. Although the end stage lasts just a week, minimum temperatures may negatively affect the yields of early-maturing (until 10 °C) and middle-maturing varieties. Maximum temperatures occurring in starting stage positively affect the yields of all varieties in nonlinear way until 14-15 °C above of which decrease (table 5). At the same time, the adverse effects have been highlighted only in maturity for late-maturing varieties and end stages for early-maturing varieties until a certain threshold, i.e., 17 °C and 13 °C, respectively.

We also estimated the impacts of statistically significant weather coefficients among earliness and phenological stages, hence, the confidence level of temperature distributions. Results show a high confidence level, highlighting no differences among coefficients

[2] Generally, the sowing date of wheat is set on the middle of November in the Mediterranean area (Allen et al., 1998)

Table 4. Effect of temperatures on yields among phenological stages and earliness of durum wheat.

	starting			growing			anthesis			maturity			end		
	EM	MM	LM	EM	MM	LM	EM	MM	LM	EM	MM	LM	EM	MM	LM
Minimum temperature															
Maximum temperature															

Notes: EM, MM, and LM indicate the early-, middle-, and late-maturing durum wheat earliness, respectively. Red cells indicate a negative impact of temperatures on yields, blue cells a positive impact, white cells for the uncaptured relationships.

Table 5. Turning points of temperatures among phenological stages and earliness (°C).

	starting			anthesis			maturity			end		
	EM	MM	LM	EM	MM	LM	EM	MM	LM	EM	MM	LM
Minimum temperature	-8+	-8+	-9+	+8-	+9-	+7-	NS	NS	NS	-10+	NS	NS
Maximum temperature	+15-	+14-	+14-	NS	NS	NS	NS	NS	-17+	-13+	NS	NS

Notes: EM, MM, and LM, indicate the early-, middle-, and late-maturing durum wheat earliness, respectively. The values show the threshold temperatures beyond which there is a change of sign in the regression estimates (table 7, in the Appendix). NS: not significant.

Table 6. Confidence levels of temperatures distribution.

	starting		growing		anthesis		maturity		end	
	em	ml	em	ml	em	ml	em	ml	em	ml
Minimum temperature	-0.50580	-0.79056	-0.41006	0.16589	0.17650	-1.11070	-	-	-0.03887	-
Maximum temperature	1.50379	0.83624	-	-	-	-	-	-	-	-

Notes: *em* indicates the differences among coefficients of early-maturing and middle-maturing varieties divided by standard errors of baseline (i.e., middle-maturing variety); *ml* indicates the differences among coefficients of middle-maturing and late-maturing varieties divided by standard errors of baseline (i.e., middle-maturing variety).

(table 6). Therefore, the temperatures' effects on yields do not vary between earliness within each phenological phase.

It follows that early-maturing varieties are the most susceptible to changes in temperature, although the general relationship between yield and temperature is the same among earliness. Damages due to low temperatures are more likely among earliness than losses due to high temperatures. Sure enough, the vegetative stage lasts about four months, while maturity about a month and ends in just a week. Therefore, it is difficult to escape from low temperatures during starting and growing stages. Although wheat crop needs low temperature to complete vernalization processes, frost events occurring toward the end of the vegetative phase may cause severe damage such as the tiller, spike number, leaf area reduction and photosynthetic capacity, leading to a heavy yield losses (Xiao et al., 2018).

CONCLUSIONS

Given the potential impact of climate change on yields, deepening the yield-weather relationships is helping farmers cope with the weather risks. Therefore, we assess the effects of temperatures on durum wheat yields among early-maturing, middle-maturing, and late-maturing varieties. We distinguished the effects across five phenological stages (i.e., starting, growing, anthesis, maturity, and end) identified through the GDD approach, starting from the middle of November as sowing date. The levels and changes in temperatures affect durum wheat yields in several ways. More specifically, upward changes in the minimum temperatures are detrimental for to yields when they occur in the starting and growing phases, regardless of the earliness. Increases in maximum temperatures are indeed positively correlated (until a threshold of 14-15 °C) with the yields if they occur in the starting stage, whereas a negative effect is found when the event occurs at the maturity for late-maturing varieties or end stage for early-maturing varieties. Generally, the impacts of chronic heat stress, i.e., high temperatures for a longer duration, are lower than the heat shocks, i.e., extreme high temperatures for a short duration (Li et al., 2013). However, early-maturing varieties provides a better adaptation under warming conditions (Mondal et at., 2013), also because they may escape from the damages due to high temperatures by anticipating the crop cycle. Cold stress may cause morphological, physiological, biochemical, and molecular modifications in wheat. Phenotypic screening of cold-tolerant genes, pre-sowing seed treatments, and exogenous application of growth hormones may be a suitable solution tolerating severe low temperature extremes (Hassan et al., 2021). In conclusion, a better knowledge of the yield-temperature relationships, along with a deeper comprehension of the informative content of the secondary data on weather dynamics, may help both the farmers for the application of agronomic strategies, and policymakers for the planning of interventions to boost uptake in innovative crop insurance, such as the WIIs. Promoting greater comprehensibility of contracts' conditions, increasing transparency of indemnities and losses, and also improving the dissemination of risk management tools among farmers, may improve the trust, hence the adoption of subsidised insurance schemes (Giampietri et al., 2020). The main limitation of our study is the neglet of the effects of temperatures events on grain quality, although this is far beyond the scope of the analysis and will be addressed in future research. Further investigations are required to assess the effects of precipitation on yields and the choice of sowing dates to cope with climate risks.

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APPENDIX

Figure 1. Main durum wheat-producing provinces in Italy. Note: the main durum wheat-producing Italian provinces in decreasing order are: Foggia (Puglia region), Campobasso (Molise region), Palermo (Sicilia region), Ancona (Marche region), Potenza (Basilicata region), Matera (Basilicata region), Enna (Sicilia region), Macerata (Marche region), Avellino (Campania region), Catania (Sicilia region), Ferrara (Emilia-Romagna region), Caltanissetta (Sicilia region), Perugia (Umbria region), Bari (Puglia region), Viterbo (Lazio region), Bologna (Emilia-Romagna region), Ravenna (Emilia-Romagna region), Brindisi (Puglia region), Siena (Toscana region), Agrigento (Siclia region), Benevento (Campania region), Grosseto (Toscana region), Pisa (Toscara region), Chieti (Abruzzo region), Trapani (Sicilia region), Teramo (Abruzza), Roma (Lazio), Barletta-Andria-Trani (Puglia region), Rovigo (Veneto), Pesaro-Urbino (Marche region) (ISTAT, 2020).

Table 2. Descriptive statistics of daily temperatures, cumulative precipitation, and yearly yield variables for 30 main durum wheat producing provinces, 2020 year.

Province	Variable	Obs.	Mean	Median	St. dev	Min	Max
	Maximum temperature	198	17.27042	16.475	3.656134	10.52143	31.60714
Agrigento	Minimum temperature	198	10.53427	9.921429	3.269273	4.15	21.2
	Yield	198	27	27	0	27	27
	Maximum temperature	198	15.0523	14.80455	4.87341	5.245454	28.81818
Ancona	Minimum temperature	198	6.42034	5.990909	4.345694	-1.463636	16.89091
	Yield	198	45.3306	45.3306	0	45.3306	45.3306
	Maximum temperature	198	15.16203	14.54545	4.195631	4.790909	28.70909
Avellino	Minimum temperature	198	8.191552	8.095455	3.676873	-.0090909	18.63636
	Yield	198	32.81769	35	3.921524	25.80645	35
	Maximum temperature	198	16.11383	15.70625	4.502608	6.375	28.525
Barletta-Andria-Trani	Minimum temperature	198	7.62822	7.15625	3.886316	-1.1625	17.4875
	Yield	198	21.92088	22	.1421842	21.66667	22
	Maximum temperature	198	15.81414	15.45833	4.549949	6.333333	29.175
Bari	Minimum temperature	198	7.309596	6.741667	3.7425	-1.9	15.99167
	Yield	198	20.24346	20	.4374887	20	21.02564
	Maximum temperature	198	15.37965	14.735	4.230869	4.54	28.35
Benevento	Minimum temperature	198	8.102222	7.995	3.768435	-.1	18.14
	Yield	198	32.00147	31.97674	.0444387	31.97674	32.08092
	Maximum temperature	198	16.79045	16.59	4.067458	8.61	28.66
Brindisi	Minimum temperature	198	8.679343	8.05	3.772157	-.2	18.74
	Yield	198	34.8064	34.52381	.5077994	34.52381	35.71429
	Maximum temperature	198	14.48802	13.37143	5.873645	2.014286	28.45714
Bologna	Minimum temperature	198	5.333694	4.835714	4.361542	-2.635714	15.53571
	Yield	198	54.32178	55.5577	2.220902	50.35106	55.5577
	Maximum temperature	198	16.8204	15.89	4.028488	9.41	32.56
Caltanissetta	Minimum temperature	198	9.514748	8.94	3.520087	2.61	22
	Yield	198	28	28	0	28	28
	Maximum temperature	198	15.20285	14.95455	4.480825	3.372727	26.70909
Campobasso	Minimum temperature	198	8.140358	8.2	3.817845	-1.163636	17.9
	Yield	198	35.76263	36	.4265517	35	36
	Maximum temperature	198	17.3101	16.73889	4.048381	9.516666	31.79445
Catania	Minimum temperature	198	8.244501	7.669444	3.742443	.3722222	19.37222
	Yield	198	28.57143	28.57143	0	28.57143	28.57143
	Maximum temperature	198	15.16586	14.795	4.622042	3.25	26.89
Chieti	Minimum temperature	198	7.781061	7.65	3.902836	-1.2	18.08
	Yield	198	32.6417	32.84671	.3684098	31.98302	32.84671
	Maximum temperature	198	16.58646	15.75455	4.356249	8.218182	32.06364
Enna	Minimum temperature	198	8.238797	7.754546	3.665236	.4818182	20.07273
	Yield	198	30	30	0	30	30
	Maximum temperature	198	15.09104	14	6.145688	1.991667	29.18333
Ferrara	Minimum temperature	198	5.57319	5.341667	4.807333	-2.8	17.08333
	Yield	198	60.20202	64	6.824827	48	64
	Maximum temperature	198	15.9456	15.52292	4.463743	5.341667	27.81667
Foggia	Minimum temperature	198	8.216098	7.877083	3.775962	-.8	18.29583
	Yield	198	31.25	31.25	0	31.25	31.25
	Maximum temperature	198	17.01996	16	4.174036	9.141176	27.51765
Grosseto	Minimum temperature	198	7.026352	6.997059	4.34386	-1.876471	16.59412
	Yield	198	38.79645	38.84181	.0815015	38.65074	38.84181

Province	Variable	Obs.	Mean	Median	St. dev	Min	Max
	Maximum temperature	198	14.77406	14.60909	4.793149	5.263637	28.03636
Macerata	Minimum temperature	198	6.397888	6.027273	4.163119	-.9909091	16.48182
	Yield	198	42.00229	42.00229	0	42.00229	42.00229
	Maximum temperature	198	16.14141	15.80333	4.373894	6.466667	30.13333
Matera	Minimum temperature	198	7.865387	7.27	3.649867	.06	17.63333
	Yield	198	29.68525	29.68525	0	29.68525	29.68525
	Maximum temperature	198	16.95558	16.17143	3.899543	9.852381	33.84762
Palermo	Minimum temperature	198	10.14218	9.728571	3.256468	3.638095	19.40952
	Yield	198	25.99503	25.99503	0	25.99503	25.99503
	Maximum temperature	198	14.29614	13.5125	4.94103	4.515	26.96
Perugia	Minimum temperature	198	5.502298	5.37	4.366943	-2.92	15.535
	Yield	198	45.45914	44.86486	1.067896	44.86486	47.36842
	Maximum temperature	198	14.78035	14.34091	4.952188	4.390909	28.68182
Pesaro-Urbino	Minimum temperature	198	6.921442	6.786364	4.275691	-.9363636	17.32727
	Yield	198	38.00858	38.00858	0	38.00858	38.00858
	Maximum temperature	198	16.72483	15.875	4.305614	7.983333	27
Pisa	Minimum temperature	198	7.081019	7.179167	4.555321	-2.35	16.78333
	Yield	198	37.21282	40.33502	5.610488	27.1819	40.33502
	Maximum temperature	198	14.74603	14.36087	4.311705	4.573913	28.35217
Potenza	Minimum temperature	198	7.983707	7.556522	3.500149	-.1913043	18.28696
	Yield	198	27.29257	27.29257	0	27.29257	27.29257
	Maximum temperature	198	14.83678	14.03182	5.718577	2.609091	28.87273
Ravenna	Minimum temperature	198	5.954132	5.440909	4.503898	-2.563636	16.74545
	Yield	198	66.57576	68	2.55931	62	68
	Maximum temperature	198	17.05811	16.0775	3.893504	9.67	27.955
Roma	Minimum temperature	198	7.608207	7.3925	4.132565	-.35	19.59
	Yield	198	29.23737	29	.4265517	29	30
	Maximum temperature	198	14.97117	13.71818	5.981333	2.472727	28.05455
Rovigo	Minimum temperature	198	5.668916	5.363636	4.904146	-2.936364	17.71818
	Yield	198	56.23271	59.41509	5.718627	46.00845	59.41509
	Maximum temperature	198	15.97519	14.77813	4.710545	6.7125	27.15
Siena	Minimum temperature	198	5.882323	5.953125	4.678793	-3.45	16.81875
	Yield	198	37.53158	38	.8417409	36.02664	38
	Maximum temperature	198	14.60795	14.2125	4.647457	3.6875	26.6625
Teramo	Minimum temperature	198	7.074495	6.925	3.945144	-1.1	17.55
	Yield	198	39.80582	39.80582	0	39.80582	39.80582
	Maximum temperature	198	17.92341	17.12143	3.75761	10.22857	33.5
Trapani	Minimum temperature	198	10.757	10.63571	3.492239	2.428571	21.32857
	Yield	198	22.90524	23.80952	1.624959	20	23.80952
	Maximum temperature	198	16.60761	15.75	4.229603	8.413333	27.76667
Viterbo	Minimum temperature	198	7.143199	6.993333	4.106516	-.5666667	17.82
	Yield	198	38.73369	38.02031	1.281932	38.02031	41.02564

Table 7. Effects of earliness on the relationship between durum wheat yield and weather conditions.

	starting			growing			anthesis			maturity			end		
	EM	MM	LM	EM	MM	LM	EM	MM	LM	EM	MM	LM	EM	MM	LM
Minimum temperature	**-0.21574***	**-0.18915***	**-0.14759***	**-0.06015***	**-0.05224***	**-0.05544***	**0.15038***	**0.13949**	**0.20802***	0.07918	-0.02572	0.00233	**-0.34243**	**-0.33464**	0.04429
	(0.05802)	(0.05257)	(0.04752)	(0.01944)	(0.01929)	(0.01927)	(0.05808)	(0.06170)	(0.06669)	(0.07492)	(0.07999)	(0.08207)	(0.19684)	(0.20040)	(0.20892)
Minimum temperature (sq)	**0.01431***	**0.01298***	**0.00917***	**-0.00322**	**-0.00413**	**-0.00298**	**-0.00987**	**-0.00865**	**-0.01692***	**-0.00880**	-0.00162	-0.00158	**0.01720**	0.01595	-0.00285
	(0.00394)	(0.00364)	(0.00335)	(0.00173)	(0.00171)	(0.00170)	(0.00446)	(0.00455)	(0.00472)	(0.00456)	(0.00469)	(0.00465)	(0.01028)	(0.01008)	(0.01005)
Maximum temperature	**0.48706***	**0.33811***	**0.25528***	0.01712	0.00387	0.00921	-0.02972	0.01816	0.13013	0.00072	-0.15447	**-0.26802***	**-0.37884**	-0.21556	-0.00099
	(0.11419)	(0.09905)	(0.08780)	(0.03572)	(0.03472)	(0.03381)	(0.07884)	(0.08382)	(0.08923)	(0.09370)	(0.09737)	(0.09974)	(0.22896)	(0.21750)	(0.22702)
Maximum temperature (sq)	**-0.01716***	**-0.01237***	**-0.00938***	0.00180	**0.00269**	0.00222	0.00275	0.00028	-0.00333	-0.00035	**0.00456**	**0.00836***	**0.01483**	**0.00983**	0.00423
	(0.00422)	(0.00375)	(0.00340)	(0.00158)	(0.00150)	(0.00143)	(0.00265)	(0.00274)	(0.00285)	(0.00271)	(0.00274)	(0.00273)	(0.00592)	(0.00549)	(0.00555)
Prov FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	6,496	7,472	8,447	34,105	35,215	36,217	10,667	10,523	10,401	12,235	12,073	11,953	3,006	3,016	2,958
No. of prov	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

Notes: EM, MM, and LM, indicate the early-, middle-, and late-maturing durum wheat earliness, respectively. Results show the estimates of the regressions model (1) for each year. Standard errors are shown in parenthesis. Phenological stages have been identified through the GDD approach, starting from November 15 as sowing date.

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Does the presence of inner areas matter for the registration of new Geographical Indications? Evidence from Italy

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Abstract. Remote areas have been progressively obtained greater attention. Since 2014, the Italian National Strategy for Inner Areas has tackled remote areas with the aim of promoting local development. A tool to foster economic development in these areas is valorisation of those high-quality agri-food products that are characterised by unique features, through the use of geographical indications. This study addresses this topic, by considering the geographical indications registered in Italy since 2014. The study considers municipality-level (LAU2) data, taking the number of geographical indications that each municipality is eligible to produce as a dependent variable. Hurdle models are used to assess the effect of inner areas and other covariates (i.e., agriculture and food industry features, socio-economic characteristics, regional settings). The results suggest that geographical indications still represent a sort of untapped resource across inner areas, even when controlling for regional settings across Italy. Thus, a more effective policy intervention is requested.

Keywords: geographical indications, inner areas, rural development.
JEL Codes: Q18, R50.

HIGHLIGHTS:

- GI registration can promote economic development in inner areas.
- Degree of remoteness negatively affects GI registration in Italian municipalities.
- Socioeconomic features of agriculture and regional differences also play a role.
- Policymakers should favour GI registration in inner areas.

1. INTRODUCTION

Due to its geographical characteristics, Italy shows large heterogeneity in terms of landscape and territory composition, turning into different conditions of accessibility to essential services, which represents a critical issue

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when considering territorial imbalances (Christaller, 1933; Bonifazi and Heins, 2003; Barca et al., 2014; Mantino, 2021). Thus, some municipalities, placed at further distance from major urban poles, suffer from socioeconomic marginalisation and underdevelopment, in comparison with larger urban areas (Bertolini and Pagliacci, 2017; SVIMEZ, 2019; Iammarino et al., 2018; De Renzis et al., 2022). For this reason, in 2014 a specific national-level strategy was included in the National Reform Programme in Italy. The National Strategy for Inner Areas (hereinafter, NSIA), supported with public funds, has targeted inner (i.e., remote) Italian municipalities, with the aim of reversing depopulation trends and socioeconomic remoteness. To achieve this goal, inner areas have been supported in the capitalisation of the existing local assets and resources, through the activation of specific place-based policy measures (Barca et al., 2014).

Among the available local resources inner areas can capitalise on, localized agri-food systems (LAFSs) can play a pivotal role (Arfini and Mancini, 2018). As other remote regions, inner areas are rich in high-quality and traditional agri-food products, whose value is based on the link between territorial features and production techniques (Barca et al., 2014). In particular, some of the pilot inner areas identified by the NSIA have already implemented some measures aimed at the valorisation of agro-food local products through the recognition of new Geographical Indications (GIs).

Originally introduced in 1992 in the EU, GIs are currently regulated under the EU Regulation 1151/2012. GIs stress the unique characteristics of the agro-food (and wine) products they protect, being a strategic tool to increase the income of the producers (Cei et al., 2021; Crescenzi et al., 2022). With 315 registered agro-food GIs and 526 registered wine GIs, Italy is the forerunner in the EU for GI registration. In terms of value-added, agro-food GIs amount to €7.97 billion, while wine GIs amount to €11.16 billion (ISMEA Qualivita. 2022). Among other goals (e.g., addressing the problem of asymmetric information between consumers and producers) (Cei et al., 2018), GIs can have positive economic effects for the involved territories, eventually favouring population and economic growth (Crescenzi et al., 2022). To this regard, registering new GIs really represent key opportunity for inner areas.

In particular, this study explores if this opportunity is actually exploited by Italian inner areas. It adopts a territorial approach, considering the agro-food GIs registered in Italy from 2014 onward (i.e., after the introduction of the NSIA) and the set of the municipalities (i.e., LAU2 areas) that are included within the boundaries of their eligible areas. By referring to municipality-level data, the analysis aims to investigate whether both territorial and socioeconomic features (e.g., characteristics of the agricultural sector and food industry; socioeconomic characteristics; regional settings and quality of the public governance) matter in the process of new GI registration, with a particular interest on the role of inner municipalities.

This paper aims to contribute to the rather scant literature that quantitatively addresses the drivers of GI registration at territorial level (Crescenzi et al., 2022; Vaquero Piñeiro, 2021; Resce and Vaquero Piñeiro, 2022; Cei et al., 2021). However, compared to previous studies, its novelty is twofold. Firstly, it explicitly addresses the role of inner areas, as defined and mapped by the NSIA (Barca et al., 2014), while previous paper mostly addressed rural areas (e.g., Vaquero Piñeiro, 2021). Secondly, its empirical strategy is grounded on the use of hurdle model, which properly handles skewed data with many zeros and admits different underlying processes to explain the zero values (i.e., registering no GIs at all at municipality level) and the positive values (Mullahy, 1986).

The rest of the paper is structured as it follows. Section 2 discusses the theoretical background, with an overview on both inner areas and the concept of GI. Section 3 describes data and the adopted method. Section 4 shows the results of the analysis, discussing them in comparison with previous studies. Section 5 concludes the work, with possible policy implications.

2. THEORETICAL BACKGROUND

This section aims to introduce some of the key concepts used in the analysis. Firstly, the characteristics of inner areas, as described and referred to by the NSIA, are introduced; then, the GIs, and their role for inner areas' development are described.

2.1 The National Strategy for Inner Areas

The NSIA represents an innovative place-based policy, aimed at promoting territorial development and cohesion in Italy. Launched in 2014 by the Italian government, it represents a nation-wide support scheme aimed at addressing remote areas' main problems, such as: remoteness, underdevelopment, marginalisation, low level of education and employment, depopulation trends (Colucci, 2019; SVIMEZ, 2019; ISTAT, 2019). More in general, it aims to reduce urban-rural disparities (Barca et al. 2014; Lucatelli 2016; Urso 2016; De Renzis et al., 2022).

Firstly, the NSIA contributes to the mapping of the Italian municipalities with the aforementioned characteristics of inner areas. A peripherality indicator – expressed as the travel-time distance from the nearest urban centre providing essential services (i.e., health, education, and transportation services) – is used to define them (De Renzis et al., 2022). In particular, a 6-class taxonomy is produced, distinguishing: urban poles (A), intermunicipal poles (B), belt areas (C), intermediate areas (D), peripheral areas (E), ultraperipheral areas (F). Classes D-F are generically labelled as 'Inner areas' (Bertolini and Pagliacci, 2017).

Secondly, since 2014 the NSIA has supported (and funded) the implementation of local development projects, based on more integrated approaches, to overcome the traditional weakness of project management in these areas (Lucatelli, 2016), and to reinforce local territorial identities (Capello, 2018). In particular, 72 pilot areas – involving at least one inner municipality – were selected on a regional basis, each of them being requested to develop its own strategy through a Project Framework Agreement. According to it, several types of local interventions were suggested as tools to promote development processes. They have involved land management, territorial safeguarding, promotion of natural and cultural assets (i.e., through sustainable rural tourism), agricultural activities (Bertolini and Pagliacci, 2017). However, to be successful, each of these interventions must capitalise on the local specificities and local resources of the involved areas, i.e., some "latent development factors" (Barca et al., 2014: 40).

Among the existing available local resources that deserve valorisation, Arfini and Mancini (2018) suggest the importance of LAFSs. In particular, valorisation of traditional high-quality agri-food products – through local participation and close cooperation among economic agents – can represent a valuable opportunity for local development across inner areas, as explicitly emphasized by the NSIA (Barca et al., 2014). Thus, it is not a case that some of the pilot areas (e.g., Alto-Medio Sannio, in Southern Italy, and Valchiavenna, in Northern Italy) have implemented their local strategies with a focus on the valorisation of agro-food products through the recognition of GIs (Agenzia per la Coesione Territoriale and Regione Molise, 2021; Agenzia per la Coesione Territoriale and Regione Lombardia, 2017).

2.2 GIs and inner areas

GIs are distinctive signs used to identify a product whose quality, reputation and traditional production techniques relate to its geographical origin (OECD, 2000; Cei et al, 2018). After having originated in Mediterranean Europe (Cei et al., 2021; Crescenzi et al., 2022), in 1992 they were introduced in the EU. Currently, they are regulated under the EU Regulation 1151/2012, hence representing one of the main elements of the EU quality policy (European Commission, 2012; Resce and Vaquero Piñeiro, 2022). GIs stress the unique characteristics of the products they protect, also addressing the problem of asymmetric information between consumers and producers (OECD, 2000; Cei et al, 2018), and affording a product protection against conflictual uses, frauds and fake imitations (EUIPO, 2017; Wirth, 2016; Crescenzi et al., 2022). As part of the high-quality schemes, GIs represent one of the pillars of the EU agricultural and food policy. For 30 years, registered GIs have steadily increased in number: in 2022, and only considering agro-food GIs, there were 1,463 registered GIs in the EU (+ 50% from 2010, according to AND-International (2019)), suggesting the ever-growing EU attention to those quality labels (Cei et al. 2021).

GIs not only prevent frauds and fake imitations. They also represent strategic tools to increase producers' income and to promote development in the territories where GI production occurs (Gangjee, 2017; Cei et al., 2021; Resce and Vaquero Piñeiro, 2022; Török et al., 2020). With regard to single producers, the price premium recognised to a GI can compensate not only the greater costs of the GI certification but also a weakness of local farmers in successfully participating in the globalized economy, hence working as a collective property right (Bojnec and Ferto,2015; Crescenzi et al., 2022). Moreover, GI implementation is proved to positively affect also the broader local communities, and the territories involved, in terms of value distribution (Belletti and Marescotti, 2017), socio-economic and environmental sustainability (Belletti et al., 2015; Cei et al., 2018), rural development (Vaquero Piñeiro, 2021), and population growth (Crescenzi et al., 2022). Given such a positive impact, they are attractive for those remote areas, looking for a "new rural development paradigm" (Ilbery and Kneafsey, 1999; Marsden, 1998). Actually, the link between GIs and the place in which they are made suggests that geographical factors – e.g., climate, soil, biodiversity – play a role together with the human factor in assuring product quality (van Leeuwen et al., 2018). Such a link is stronger for Protected Designation of Origin (PDO) than for Protected Geographical Indication (PGI)[1], but in both cases GIs represent an effective way to preserve local cultural heritage (European Commission, 2020).

[1] In the case of PDOs, every part of the production, processing and preparation process must take place in the defined region. In the case of PGIs, at least one of these stages must take place in the defined region.

In more general terms, registering a new GI can be considered as a "collective" production process (Teil, 2012: 497), turning into a "type of collective property" (Barham, 2003). Due to the length and the cost of the application procedure (Cei et al., 2021), the whole local-level community must be actively involved in this process (Prévost et al., 2014), which must be driven by the interests of multiple stakeholders, including local policymakers, local communities, agri-food producers, and even marketers and consumers (Castellò, 2021). Such a collective organization is crucial not only for the initial registration of a GI but also for its ongoing management over time (Reviron and Chappuis, 2011), for example in the case of non-minor amendments involving changes in the boundaries of the production area (Landi and Stefani, 2015). Mantino and Vanni (2018) also show the importance of the support from local administrations and local politics, by means of two case studies from Northern and Southern Italy.

Thus, it is clear that, when analysing the process of registration of new GIs, several factors play a role. Actually, analysing the main conditions that favour GI registration is complex, due to little availability of economic data on GIs at the local level. Because of these limitations, previous studies addressing this nexus were mostly qualitative (see, for example, Torok et al., 2020; Bonanno et al., 2019). However, they all confirm that socio-economic determinants (e.g., infrastructure endowment and consumer demand), dynamism of the local agri-food sector, and favourable institutional context all matter (Huysmans and Swinnen, 2019; Meloni and Swinnen, 2018; Vaquero Piñeiro, 2021; Resce and Vaquero Piñeiro, 2022). Also, farmers' characteristics matter for GI registration, and in particular: famers' education level (Marongiu and Cesaro, 2018), and propensity to cooperate (Charters and Spielmann, 2014; Cei et al., 2021; Vaquero Piñeiro, 2021). Lastly, also pre-existing experience in GI registration matters: traditional GI regions tend to be more active in new GI registration, thanks to accumulation of skills among producers and improved institutional capacity (Cei et al., 2021; Tregear et al., 2016; Huysmans and Swinnen, 2019). Also, Kizos et al. (2017) claim that implementation of GIs in those territories having experienced GIs registration for decades is even more developed thanks to the presences of consortia and pre-existing collective actions.

All these elements can be grouped under the general (albeit rather fuzzy) definition of social and territorial capital, whose importance for agricultural and rural development has been largely emphasized over time (Putnam et al., 1994; Capello, 2018; Rivera et al. 2019; Cortinovis et al. 2017; Pagliacci et al., 2020).

When considering the aforementioned territorial and socioeconomic characteristics, remoteness cannot be ignored as a major driver, due to the specificities that characterize inner areas. Indeed, when considering GI registration in inner municipalities, contrasting findings emerge. These areas are endowed with some crucial factors, but can lack some others. At EU level, many studies have claimed that GI registration represents an economic opportunity largely exploited by remote and other less favoured areas (Parrott et al., 2002; Santini et al.; 2015; van de Pol, 2017; Cei et al., 2021). However, in the case of Italy, a positive nexus between GIs and inner areas is less obvious. According to Marongiu and Cesaro (2018), Italian farmers located in the less favoured areas (i.e., remote and inner regions, among other) are less likely to engage in GI schemes than those located close to the flatlands, hence benefitting from a larger infrastructure endowment. Similarly, Vaquero Piñeiro (2021) claims that the Italian food PDOs with the highest revenues come from those municipalities that show better socio-economic conditions, a more diversified economy and a more competitive agri-food sector.

3. DATA AND METHODS

This section aims to discuss the data adopted into the analysis together with the suggested method.

3.1 Data

This study considers all the agro-food GIs (both PDOs and PGIs) that have been registered in Italy, since 2014, i.e., the year of introduction of the NSIA. Specifically, the study takes into account all GIs registered in both northern and southern Italy, regardless of the extent of the territory specified by each GI's Product Specification (i.e., considering both GIs produced in only a few municipalities and those produced in entire regions[2]), in order to have a more general overview of the possible different factors playing a role in new GI registration.

However, this study only considers agro-food GIs, excluding wine GIs. Two main reasons drive this choice. Firstly, previous studies tackling GIs and their territorial distribution have favoured wine GIs more than food GIs

[2] Despite its focus, this analysis also includes the GIs produced over entire regions. Actually, although inner municipalities usually play a limited role in the decisions to register new large-scale GIs, however their inclusion within the boundaries of the area of production can still represent an important decision, eventually prompting local economic development.

Table 1. Number of GIs, by type (PDO and PGI) and product category.

	PDO	PGI	Total
Fruit, vegetables and cereals	4	16	20
Cheeses	8	1	9
Bread, pastry, cakes, …	1	7	8
Oils and fats		6	6
Meat products		6	6
Pasta		3	3
Other products of animal origin	1		1
Fresh meat (and offal)		1	1
Chocolate and derived products		1	1
Fresh fish, molluscs, and crustaceans	1		1
Total	15	41	56

(see for example Resce and Vaquero Piñeiro, 2022; Crescenzi et al., 2022). Secondly, an analysis on agro-food GIs – which include very different products (e.g., fruits and vegetables, cheeses, meat-based products) – can shed light on a broader set of territorial and social determinants of the degree of protection sought through GI labels, hence favouring more generalisable findings.

In total, we consider 56 GIs, of which 15 are PDOs and 41 are PGIs. As shown in Table 1, 10 different product categories are included. Most of the GIs under analysis are fruit, vegetables and cereals. However, when considering PDOs only, most of them are cheeses. For each of them, we retrieved the list of municipalities included within the boundaries of the eligible area of production according to each single GI's Product Specification (as retrieved by the eAmbrosia dataset[3]).

Considering the agro-food GIs registered in the 2014-2022 period, there are 4125 Italian municipalities (out of 7926) that are eligible for the production of at least one of them. In particular, some municipalities in Tuscany and in Apulia are eligible to produce even four different newly registered GIs (Figure 1).

GI eligibility at municipality level can be jointly analysed with the Italian inner municipalities (Table 2). On average, 46.8% of the Italian municipalities are included in the production area of none of the GIs registered in the period 2014-2022. However, this share is the largest in the intermunicipality poles (B) and belt areas (C), i.e., across some types of non-inner areas. Conversely, it is definitely lower in type D, E, and F municipalities. These results seem suggesting that inner areas are more likely to adopt new GIs than non-inner areas.

[3] Available at https://ec.europa.eu/info/food-farming-fisheries/food-safety-and-quality/certification/quality-labels/geographical-indications-register/.

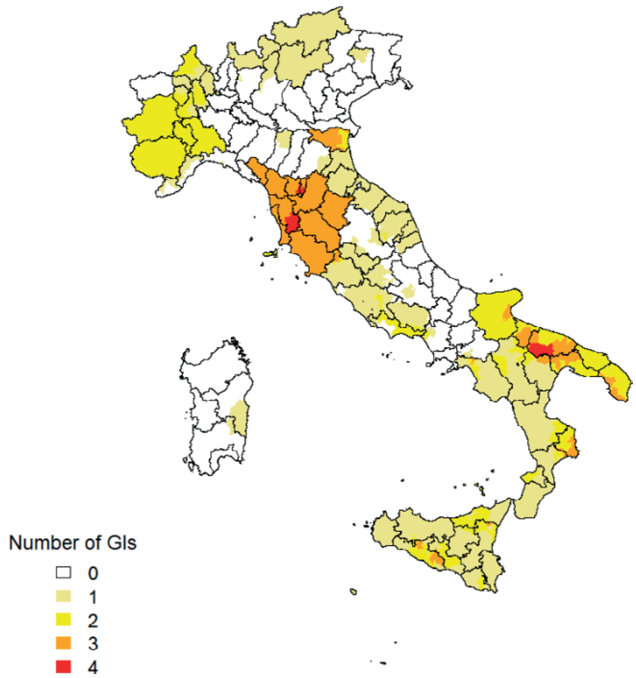

Figure 1. Number of registered GIs (2014-2022), by municipality.

Table 2. Share of municipalities with no registered GIs, by type of inner-area municipality, out of the number of municipalities in each type of inner-are

	Value (%)
A – Urban poles	41.9
B – Intermunicipality poles	59.0
C – Belt areas	54.1
D – Intermediate areas	40.4
E – Peripheral areas	42.0
F – Ultraperipheral areas	32.9
total average	46.8

Source: own elaboration.

3.2 Methods

To assess the role of the drivers that may affect the number of newly registered GIs at municipality level, the following empirical strategy is adopted.

As a dependent variable, the number of agro-food GIs registered in the 2014-2022 period, by Italian municipality, is a count variable. It is not normally distributed, as it includes many zero observations (46.8% of the total observations). In this case, it is common to adopt a count regression approach. The basic distribution for a count variable is a Poisson distribution, with the conditional mean (the mean of the outcome variable

Y given the values of the predictor variables X) being equal to the conditional variance (Cameron and Trivedi, 2013). However, given the clear stack of zero values in the dependent variable in this case, Poisson models tend to show poor fitting. Thus, the hurdle model, i.e., a modified count model, can help (Mullahy, 1986). It is a two-part model. Firstly, the zero hurdle part is adopted to model a right-censored outcome variable indicating municipalities being eligible for not even a single GI (Y = 0) or with at least one of them (Y = 1, where all values larger than 0 are censored, i.e., are fixed at 1). The second part is a truncated count, which is adopted to model the exact number of GIs for those municipalities that are eligible for producing at least one of them (municipalities with Y > 0).

The hurdle model is also based on the idea that different underlying processes – driven by different sets of regressors – can explain either the zero values and the positive values of this variable. If a municipality does not produce a single GI, then the threshold (i.e., the 'hurdle') to the truncated count part is not crossed, and a zero value is observed. Otherwise, the hurdle to the truncated count part is crossed, and any given number can be observed. In the case of GI registration, it might be expected that those municipalities that have already been included in the area of production of one GI, might benefit from further facilitation in registering additional GIs, compared to other municipalities (see Cei et al., 2021; Kizos et al., 2017).

Dealing with the research question of this study, the hurdle model combines a binomial probability model – governing the binary outcome of whether a count variable has a zero or a positive value – with a zero-truncated Poisson count-data model, for those observations that cross the hurdle (Y >0). Formally, we have (Zeileis et al., 2008):

$$f_{hurdle}(y; x, z, \beta, \gamma) = \begin{cases} f_{zero}(0; z, \gamma) & if\ y = 0 \\ 1 - f_{zero}(0; z, \gamma) \cdot \dfrac{(f_{count}(y; x, \beta))}{(1 - f_{count}(y; x, \beta))} & if\ y > 0 \end{cases} \quad (1)$$

Where the model parameters are estimated by Maximum Likelihood, and where the specification of the likelihood has the advantage that the count and the hurdle component can be maximized separately (Zeileis et al., 2008). The corresponding mean regression relationship is given by using the canonical log link, resulting in a log-linear relationship between mean and linear predictor (Zeileis et al., 2008):

$$\log \mu_i = x_i^T \beta + \log(1 - f_{zero}(0; z_i, \gamma)) - \log(1 - f_{count}(0; x_i, \beta)) \quad (2)$$

With regard to the empirical strategy implemented here, different models, including different sets of regressors, grounded on the literature review carried on in Section 2, are used.

Model 1 focuses on the role of inner areas, referring to the 6-class taxonomy of the Italian municipalities produced by the NSIA. Model 2 considers the characteristics of the agriculture sector (i.e., utilised agricultural area per inhabitant, share of cooperative agricultural holdings out of the total, share of agricultural holders aged 40 years and less out of the total, share of agricultural holders having achieved tertiary education) and of the food industry (i.e., share of employment in food industry of the total manufacturing industry employment). Moreover, the share of agricultural holdings being already involved in PDOs or PGIs production (considering 2010 Census data) is included as a proxy of any pre-existing experiences in GI registration. Model 3 includes socio-economic characteristics of the municipality, addressing average per capita income (in 2014) as a proxy for the local-level socioeconomic dynamism, and share of electoral turnout in the EU 2014 vote, as a more general proxy for social capital at local level[4]. Lastly, Model 4 is the most comprehensive model, including all the aforementioned covariates. Lastly, it can be noticed that in all the Models 1-4, a categorical variable distinguishing the Italian Macro-regions (i.e., North-West, North-East, Centre, South and the Islands) is also included. Such a variable is important to address different regional settings. Indeed, Italian macroregions largely differ in terms of climatic conditions, characteristics of the agricultural sector and of the supply chains, and institutional settings (eventually affecting overall governance and politics quality). This categorical variable is expected to control for all these aspects.

For each of the aforementioned regressors, Table 3 provides variable specification as well as data source.

4. RESULTS AND DISCUSSION

The results of the hurdle models, in each specification, are returned with regard to the coefficients of the variables (Table 4) and the estimated odd ratios (Table 5).

In Model 1, the baseline odds of having a positive count (i.e., at least one eligible GI, by municipality) are 1.27. The odds are affected negatively by being either

[4] Actually, EU voting does not lead to any direct economic rewards, being mostly driven by a sense of public duty (Bigoni et al., 2016; Guiso et al., 2004; Putnam et al., 1994). Moreover, one could also argue that a higher electoral turnout in the elections could refer to the presence of a higher-quality political class as well.

Table 3. Covariates for the analysis at municipality level.

Group	Label	Descriptions	Specification	Source	Year
Remoteness	INNER AREAS	Categorical variable, reflecting inner area type of Italian municipalities (A-urban poles, B-intermunicipal poles, C-belt, D-intermediate, E-peripheral, F-ultraperipheral), according to the NSIA classification	6 factors	Own elaboration on Barca et al. (2014)	2014
Agriculture and food industry	UAA	Hectares of Utilised Agricultural Area (UAA) per inhabitant (2010)	Ratio	Italian Agricultural Census (Istat)	2010
	COOP	Share of cooperative agricultural holdings out of the total	Ratio	Italian Agricultural Census (Istat)	2010
	YOUNG	Share of agricultural holders aged 40 years and less	Ratio	Italian Agricultural Census (Istat)	2010
	UNIVERSITY	Share of agricultural holders having achieved tertiary education	Ratio	Italian Agricultural Census (Istat)	2010
	FOOD_IND	Share of employment in food industry of the total manufacturing industry employment	Ratio	Italian Population and Housing Census (Istat)	2011
	PAST GIs	Share of agricultural holdings being involved in PDOs or PGIs production in 2010	Ratio	Italian Agricultural Census (Istat)	2010
Socio-economic characteristics	INCOME	Average gross taxable income (thousand €), for year 2014	continuous (1000€)	Ministero dell'Economia e delle Finanze	2014
	ELECTION	Share of electoral turnout in the 2014 EU vote	Ratio	Ministero dell'Interno	2014
Regional settings	MACRO_REG	Categorical variable, for the Italian macroregion (North-west, North-east, Centre, South, the Islands)	5 factors	ISTAT	2011

an intermunicipal pole (type B) or a belt area (type C), while this odds ratio is 1.805 times higher in the ultraperipheral municipality (type F). Controlling for *MACRO_REG*, odds ratio is 8.030 times higher in Central regions while being located in the North-East decreases it by 0.399 times. Given the response is positive (i.e., the hurdle is crossed), the negative effects played by *INNER AREA* are largely observed: intermediate (type D), peripheral (type E) and ultraperipheral (type F) municipalities are associated with a smaller number of newly registered GIs. When controlling for *MACRO_REG*, North-Eastern regions, Southern regions and the Islands are associated to a smaller number of GIs as well.

In Model 2, the baseline odds of having a positive count are positively affected by *UAA* and *FOOD_IND*, while *COOP* has a negative effect, despite common expectations. Controlling for *MACRO_REG*, these odds is higher in Central regions and smaller in the North-East, as observed in Model 1. Given the response is positive, *UAA* and *PAST GIs* increase the number of registered GIs in each municipality, while *YOUNG* and *FOOD_IND* negatively affect it. With regards to *MACRO_REG*, same effects, as observed in Model 1, are found.

In Model 3, the baseline odds of having a positive count are negatively affected by *INCOME* and *ELECTION*, also when controlling for *MACRO_REG* (whose coefficients are all significant). However, given the response is positive, both *INCOME* and *ELECTION* turns to positively affect the number of registered GIs in each municipality.

In Model 4, most of previous effects are largely confirmed. The baseline odds of having a positive count are 21.957. Compared to urban poles, all other municipality types reduce these odds, with the only exception of ultraperipheral municipalities (type F), showing no significant effect at all. Moreover, it is also significantly decreased by *COOP*, while both *UNIVERSITY* and *FOOD_IND* positively affect it. Among socioeconomic characteristics of the municipalities, *ELECTION* negatively affects it. When considering *MACRO_REG*, North-East is confirmed to have a negative effect on these odds, as South and the Islands have. Conversely, being a municipality in the Centre increases the odds. Given the response is positive (i.e., the hurdle is crossed), the negative effects played by *INNER AREA* is much broader and generalised. Inner municipalities (D-F) show a lower number of registered GIs. Conversely, *UAA* and *PAST GIs* increase the number of registered GIs in each municipality (confirming the findings form Model 2), and also *ELECTION* turns to positively affect this number.

The results about the new GI registration in Italy, in years 2014-2020, confirm most of the findings from pre-

Table 4. Model estimates for the number of GIs at municipality level.

Variable	M1		M2		M3		M4	
	Count model	Zero hurdle model	Count model	Zero hurdle model	Count model	Zero hurdle model	Count model	Zero hurdle model
(Intercept)	0.380 ***	0.243	0.144 *	-0.054	-0.968 ***	2.800 ***	-0.355	3.089 ***
	(0.102)	(0.154)	(0.057)	(0.064)	(0.182)	(0.221)	(0.243)	(0.320)
INNER AREAS _ type B	0.369 *	-0.898 ***					0.374 *	-1.018 ***
	(0.154)	(0.154)					(0.154)	(0.257)
INNER AREAS _ type C	-0.166	-0.389 *					-0.158	-0.630 ***
	(0.102)	(0.155)					(0.105)	(0.158)
INNER AREAS _ type D	-0.389 ***	0.070					-0.358 **	-0.360 *
	(0.104)	(0.157)					(0.110)	(0.165)
INNER AREAS _ type E	-0.491 ***	0.082					-0.451 ***	-0.438 *
	(0.111)	(0.160)					(0.119)	(0.171)
INNER AREAS _ type F	-0.870 ***	0.590 **					-0.852 ***	0.104
	(0.178)	(0.198)					(0.185)	(0.206)
UAA			0.008 °	0.030 *			0.021 ***	-0.008
			(0.005)	(0.013)			(0.005)	(0.011)
COOP			0.013	-0.077 **			0.010	-0.077 **
			(0.025)	(0.028)			(0.025)	(0.028)
YOUNG			-0.007 **	0.000			-0.004	-0.004
			(0.003)	(0.003)			(0.003)	(0.003)
UNIVERSITY			0.002	0.000			-0.004	0.014 ***
			(0.003)	(0.004)			(0.004)	(0.004)
FOOD_IND			-0.002 *	0.005 ***			-0.001	0.003 **
			(0.001)	(0.001)			(0.001)	(0.001)
PAST Gis			0.006 ***	0.000			0.006 ***	-0.001
			(0.001)	(0.001)			(0.001)	(0.001)
INCOME					0.033 ***	-0.116 ***	0.015	-0.109
					(0.008)	(0.010)	(0.009)	(0.011)
ELECTION					0.007 ***	-0.008 ***	0.006 ***	-0.006 **
					(0.002)	(0.002)	(0.002)	(0.002)
MACRO_REG_North-east	-1.806 ***	-0.919 ***	-1.978 ***	-0.835 ***	-1.776 ***	-1.002 ***	-1.831 ***	-1.020 ***
	(0.163)	(0.070)	(0.163)	(0.071)	(0.164)	(0.071)	(0.165)	(0.074)
MACRO_REG_Centre	0.040	2.083 ***	0.021	2.128 ***	0.092 °	1.914 ***	0.089	1.809 ***
	(0.049)	(0.114)	(0.052)	(0.114)	(0.050)	(0.115)	(0.057)	(0.118)
MACRO_REG_South	-0.258 ***	0.002	-0.283 ***	0.076	-0.051	-0.623 ***	0.003	-0.757 ***
	(0.056)	(0.063)	(0.061)	(0.066)	(0.074)	(0.086)	(0.083)	(0.094)
MACRO_REG_Islands	-0.664 ***	-0.123	-0.720 ***	-0.001	-0.452 ***	-0.745 ***	-0.342 ***	-0.928 ***
	(0.097)	(0.087)	(0.100)	(0.086)	(0.111)	(0.111)	(0.119)	(0.117)

Note: For count model, truncated Poisson with log link; For Zero hurdle model, binomial with logit link.
For INNER AREAS: omitted type A single 'poles'
For MACRO_REG: omitted type North-West
Significance: °p<0.1; *p<0.05; **p<0.01; ***p<0.001
Source: own elaboration.

vious studies. Surely, geographical and territorial divides across Italy matter. The results about inner areas are somehow contrasting. Also, when controlling for other socioeconomic covariates, being an inner municipality generally decreases the chance of having a GI registered. Moreover, even when one new GI is registered, inner areas tend to be associated to a smaller number of registered GIs, per municipality. In fact, this finding contrasts with what observed by Parrott et al. (2002) and by Cei et al. (2021), who considered Gi adoption in the EU

Table 5. Results of the models: odd ratios.

Variable	M1		M2		M3		M4	
	Count model	Zero hurdle model	Count model	Zero hurdle model	Count model	Zero hurdle model	Count model	Zero hurdle model
(Intercept)	1.462	1.274	1.155	0.948	0.380	16.442	0.701	21.957
INNER AREAS _ type B	1.447	0.408					1.453	0.361
INNER AREAS _ type C	0.847	0.678					0.853	0.533
INNER AREAS _ type D	0.678	1.072					0.699	0.698
INNER AREAS _ type E	0.612	1.086					0.637	0.646
INNER AREAS _ type F	0.419	1.805					0.426	1.110
UAA			1.008	1.031			1.021	0.992
COOP			1.013	0.926			1.010	0.926
YOUNG			0.993	1.000			0.996	0.996
UNIVERSITY			1.002	1.000			0.996	1.014
FOOD_IND			0.998	1.005			0.999	1.003
PAST Gis			1.006	1.000			1.006	0.999
INCOME					1.034	0.891	1.015	0.897
ELECTION					1.007	0.992	1.006	0.994
MACRO_REG_North-east	0.164	0.399	0.138	0.434	0.169	0.367	0.160	0.361
MACRO_REG_Centre	1.041	8.030	1.022	8.396	1.096	6.778	1.093	6.102
MACRO_REG_South	0.773	1.002	0.754	1.079	0.951	0.536	1.003	0.469
MACRO_REG_Islands	0.515	0.884	0.487	0.999	0.636	0.475	0.711	0.395

For INNER AREAS: omitted type A single 'poles'
For MACRO_REG: omitted type North-West
Source: own elaboration.

less favoured areas. Rather, this finding is more in line with the results by Marongiu and Cesaro (2018). A possible explanation for these contrasting results might lie in the different geographic areas (i.e., considering Italy only) and in the different territorial scale adopted (the municipality level, i.e., a narrower territorial area).

When considering other socioeconomic and territorial drivers, the findings from this study seem confirming previous ones. For example, the results about farmers' education, proxied by the share of agricultural holders with tertiary education, confirm those by Marongiu and Cesaro (2018). Conversely, cooperation in the agricultural sector shows detrimental effect in having at least one registered GI at municipality level. This finding is contrasting with previous results (Charters and Spielmann, 2014; Cei et al., 2021; Vaquero Piñeiro, 2021) and largely unexpected: lack of cooperation among farmers is usually recognised as a major issue in the registration process of high-quality agri-food products, which ground on consortia for their protection and valorisation (see also Fasano, 2021, for a qualitative study analysing some agri-food products of the Molise region and the efforts to register new GIs in Southern Italy's inner areas). It is not a case that improving collective actions in agriculture represents a key objective of the Common Agricultural Policy (CAP) in 2023-2027 programming period. Conversely, the positive role played by pre-existing experience in registering GIs confirms the findings of Cei et al. (2021), Tregear et al. (2016), and Huysmans and Swinnen (2019). Moreover, this study seems suggesting that accumulation of skills among producers and improved institutional capacity is even more important in explaining the registration of more and more GIs, thus confirming the vitality of traditional GI regions.

In the case of the proxies for social capital endowment at local level, electoral turnout in EU vote shows a significant effect, albeit with contrasting sign in either the zero-part or the count-part of the model. The fact that electoral turnout can play a positive role in explaining the registration of more and more GIs, when at least one is registered, can be explained by the fact that quality of local political institutions also matter, with a sort of multiplying effect. Actually, a greater quality of local institutions can increase citizens' trust in the local political class, positively affecting in turn electoral turnout, also in EU elections. The nexus between electoral turnout, quality of institutions and GI registration is somehow consistent with the idea of GIs as collective properties (Barham, 2003), which calls for a high level of social capital for their implementation.

These results are somehow consistent with those about the differences observed across Italian macroregions. Southern Italian regions and the Islands tend to show lower propensity to register new GIs, and they are also characterised by a smaller number of registered GIs per single municipality, when at least one has been registered. As already observed, several reasons might explain these differences across Italian macroregions, including different climatic conditions, different structures of the supply chains, different institutional settings and quality of the local governance. In particular, several authors have stressed the importance of this latter hypothesis. Indeed, Vaquero Piñeiro (2021), Meloni and Swinnen (2018) and Crescenzi et al. (2022) point out the role of institutional quality in GI registration. When considering single cases studies, also Mantino and Vanni (2018) suggest the importance of the attitude of the local policy system, finding same differences when comparing Northern and Southern regions.

Overall, these results could perhaps challenge the willingness of the policymakers (both at EU and national level) to provide a tool, such as GIs, to foster remote areas' development. In particular, given the negative relationship between inner areas and the number of registered GIs, the effectiveness of many of the strategies implemented at local level by the 72 pilot inner areas might seem not effective at all (see Dipartimento per le politiche di coesione, 2020). Especially across Southern Italy, promotion of agro-food quality systems is considered relevant and supported by local policymakers. However, the existence of some major weaknesses in the inner areas (e.g., remoteness, scarcity of agricultural modernisation, presence of elderly farmers in the inner areas) seems to overcome any political will. Thus, in the case of Italian inner areas, not even the NSIA has been able to revert these weaknesses, hence turning into a still too limited exploitation of GI registration.

5. CONCLUSIONS AND POLICY IMPLICATIONS

In order to foster socioeconomic development and agriculture diversification of inner areas (as of other marginal areas), EU quality schemes for agro-food products (and GIs in particular) are considered as a key opportunity, by both EU and national policymakers. Actually, inner areas share a large amount of natural resources as well as of traditional agro-food products, which might benefit from GI protection. In particular, this paper has contributed to the empirical debate of the territorial and socioeconomic drivers that can affect GI registration in Italy (i.e., the frontrunner country in the EU), by demonstrating which of them play the most prominent role. By considering the number of agro-food GIs registered across Italian municipalities in years 2014-2022, and by using hurdle models, this study suggests that this opportunity still represents a sort of untapped opportunity for Italian inner areas, despite the strong political commitment to promote them. Moreover, future works will try to extend these findings to other national contexts, as well as to include also the wine sector.

However, it should be noticed that not even the inclusion in the area of production is necessarily a guarantee of production exploitation of the GI for the municipality itself. Actually, GI producers are free to locate in any municipalities within the boundaries of the production area, eventually favouring non-inner municipalities. Nevertheless, being included within the area of production of a GI (even in the case of larger scale GIs) might represent a key element for any communities that aim to create a collective property, as GIs are. Therefore, this inclusion represents a tool to add value to the local agro-food production. As suggested by this study, in addition to geographic remoteness, other factors might hinder this process, e.g., the lack of local-level political commitment, and the limited extent of social capital at local level. However, further studies will also tackle the location of the producers within the boundaries of the production area, to test their effective links with inner areas.

However, even if just considering municipality eligibility, it is clear that, in order to enhance a stronger registration of new GI labels across Italian inner areas, the CAP should put more attention on this nexus. However, the Italian CAP Strategic Plan for the 2023-2027 programming period has not included any radical innovations in the way quality schemes are supported by EU public funds. In addition to specific funds, what seems to be really important to achieve these ambitious goals is fostering cooperation among farmers and between producers and policymakers, who must have an even more proactive role in raising awareness of the GI potential, even in the inner areas. Such an approach would be useful to get the chance to use this untapped potential, hence promoting a more efficient and a more cohesive food chain organisation also across inner areas.

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Learning, knowledge, and the role of government: a qualitative system dynamics analysis of Andalusia's circular bioeconomy

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Abstract. The transition from a linear bio-based economy to a sustainable circular bioeconomy depends not only on the skills that the different actors of the innovation system can find, develop, and exploit internally, but also on the efficiency with which they can access external sources of knowledge and skills related to technologies and markets. In this scenario, understanding the dynamics of learning and knowledge accumulation acquires greater importance due to the bioeconomy's position at the confluence of several technological areas. Therefore, for this study, we apply qualitative system dynamics modelling methods to the analysis of Andalusia's circular bioeconomy, obtaining important insights into its complexity due to the existence of non-linear processes, multiple feedback loops, and time delays. The models thus generated led to the identification of 20 key intervention points where targeted actions by governments and other actors could help overcome the pervasiveness of information asymmetry in the sector.

Keywords: bioeconomy, system dynamics, knowledge, innovation systems, government.
JEL Codes: O1, O2, O3.

1. INTRODUCTION

A common feature observed in government strategies for the development of a bio-based economy is the belief that a strong innovation system will play a key role in the realization of the sector's potential. In this context, the dynamics of learning and knowledge accumulation is critical and presents a key challenge as the bioeconomy is largely composed of companies with persistently low levels of digitalization (Bacco et al., 2019) and struggling to develop effective business models (Reim et al., 2019). For over 30 years, the innovation systems approach (Lundvall, 1992; Nelson, 1992) has provided an important theoretical framework to explain the complex interactions that take place between the different participants of the innovation process as well as the basis for policymaking in the fields of science, technology, innovation, and economic development. This concept has enjoyed vast popularity for the many advantages that it offers over the traditional linear models developed in the previous four decades. However, the inner dynamics of innovation systems remain somewhat unexplored, largely because innovation studies have often pursued a linear thinking approach while the innovation process is known to follow non-linear paths and involve feedback loops across all the stages.

On the other hand, while a significant share of publications and government strategies consider the bioeconomy as being intrinsically sustainable (Global Green Growth Institute, 2020; Motola et al., 2018), various experts have expressed concerns that a linear business-as-usual approach to the bioeconomy can have negative impacts if the principles of a circular economy are not followed (Bosch et al., 2015; OECD, 2014; Pfau et al., 2014; Philp, 2018; Reim et al., 2019). In response to these discussions, the term "circular bioeconomy" was created, and some attempts have been made to define the concept but clear guidance for bioeconomy practitioners is still needed (Stegmann et al., 2020). A circular economy aims to maintain the value of products, materials, and resources as much as possible while minimising the generation of waste (European Commission, 2015), thus requiring interactions across several domains and the involvement of multiple players. However, despite this complexity, most of the analyses conducted until very recently have addressed the processes and components of innovation systems for the development of a circular bioeconomy in isolation. This is changing through the application of system dynamics modelling tools.

The system dynamics modelling approach was created during the late 1950s and early 1960s to understand the non-linear behaviour of complex systems and build models that capture their dynamic nature over time (Forrester, 1961; Meadows, 2009; Sterman, 2000). It provides powerful tools to examine cause-and-effect relationships, feedback mechanisms, non-linear effects, time delays and, accordingly, high complexity. Applications of system dynamics are increasingly found in a wide range of areas, including manufacturing, construction, infrastructure, software development, healthcare, population studies, waste management, water resources management, ecological and economic systems, and environmental management, among many others (Andersson et al., 2002; Biroscak et al., 2014; Elsawah et al., 2017; Guo et al., 2001; Hakim et al., 2016; Hsieh and Chou, 2018; Ketzer et al., 2020; Kim and Andersen, 2012; Lai et al., 2017; Layani et al., 2021; Linnéusson, 2009; Magalhães et al., 2018; Mahato and Ogunlana, 2011; Oriama and Pyka, 2021; Papachristos, 2019; Phan et al., 2021; Pitoyo et al., 2018; Sahin et al., 2017, 2018; Soydan and Oner, 2012; Stave, 2010; Stave and Kopainsky, 2015; Walz et al., 2016; Zhou and Liu, 2015). This approach has started to find application also in the study of sectoral innovation systems and processes (Allas, 2014; Allena-Ozolina and Bazbauers, 2017; Aparicio et al., 2016; Bergek et al., 2008; Candido et al., 2017; Grobbelaar, 2005, 2006; Maldonado, 2012; Milling, 2002; Moizer and Towler, 2007; Rodríguez and Navarro Chávez, 2011; Sixt et al., 2018; Suprun, 2018; Suprun et al., 2018, 2019; Uriona et al., 2012; Uriona and Grobbelaar, 2016; Walrave and Raven, 2016; Walz et al., 2016), but a recent review of the literature (Uriona and Grobbelaar, 2019) found that the contribution of the system dynamics approach to research on innovation systems has been limited and that, despite the high value offered by these tools, system dynamics modelling has not yet had the expected scientific impact in this domain.

Similarly, while there is a growing understanding that the application of linear approaches to analyze the complex mechanisms and interactions that occur in the development of the bioeconomy are often insufficient to get a good grasp of the dynamics governing this transition, systems thinking methods have only recently started to be applied in the study of these pathways (Bennich et al., 2018a, 2018b; Blumberga et al., 2018; Stark et al., 2022). Work in this field is just beginning and, as a result, there is a myriad of areas where important research gaps exist. Thus, for example, despite the broad recognition that the bioeconomy is a knowledge-intensive sector that depends largely on public policies and programs, the systems thinking approach has found virtually no application to date in the literature about learning, knowledge, and the role of government in the transition to a circular bio-based economy (see Methodology, below).

Against this backdrop, our study seeks to increase the understanding of how the dynamics of innovation systems influence the development of the circular bioeconomy, exploring how knowledge and learning influence the performance of these processes, and identifying points where interventions could enhance the strengths and overcome the weaknesses to promote growth in this sector of the economy. We focus our analysis on the Andalusian bioeconomy because it is a key component of the region's economy, generating an annual turnover of about 29 billion euros and employing around 300.000 people (approximately 9% of the total) (Institute of Statistics and Cartography of Andalusia, 2022). The significance of this sector led the Regional Government of Andalusia to release a circular bioeconomy strategy in 2018 and become one of the first regions in Spain to acknowledge the opportunities that it offers for sustainable growth and competitiveness (Regional Government of Andalusia, 2018).

To achieve our objective, we address the following questions:

1) What are the underlying causal structures and feedback mechanisms that interact dynamically in Andalusia's bioeconomy system to shape the transition to a circular bio-based economy in the region?
2) What potential learning and knowledge-related points exist in the system where targeted interventions could have significant impact?
3) What priority actions could be implemented at the identified intervention points that would have the highest probability of positive impact?
4) From a systems thinking perspective, what is the role of government in the transition to a circular bio-based economy?

2. METHODOLOGY

We apply qualitative systems modelling methods (Meadows, 2009; Sterman, 2000) to analyze Andalusia's circular bioeconomy and to conduct a qualitative assessment of key learning- and knowledge-related intervention points to develop this sector. System dynamics models are well-suited for the representation of this type of system as they allow us to analyze complex situations, applying a comprehensive view of the whole and at the same time examining the causal relationships among each of its parts. Furthermore, they provide a valuable tool to build theory around behaviours observed within a system and assess the potential impact that management and policy actions could have on it.

In this study we use causal loop diagrams (CLDs) as they are an easy and powerful tool used in system dynamics modelling to provide a visual representation of the elements of a system, their interdependency relationships, and the feedback processes that exist between them. A CLD comprises a set of variables that are connected by arrows that are assigned either a positive (+) or negative (-) sign, according to how a dependent variable is affected when an independent variable changes. The connected variables, in turn, can form positive and negative feedback loops, which are at the heart of system dynamics. These loops are positive or "reinforcing" (R) when a change in a variable circulates along the loop in a way that it reinforces the initial variation, generating growth or acceleration and having a destabilizing effect. And they are negative or "balancing" (B) when a change in a variable circulates along the loop in a way that counteracts the initial variation, acting as a stabilizing force. A feedback loop is deemed to have a reinforcing effect when all the relationships are positive or if it contains an even number of negative links, and it has a balancing effect if it contains an odd number of negative links. Lastly, the existence of lags in the cause-effect relationships between variables is another key aspect of system dynamics and implies that the effects of a change in a variable become evident not immediately, but after some time. A time delay is indicated in a CLD by a perpendicular double line marked in the arrow where it takes place.

Our methodology comprised four steps, as illustrated in Figure 1 and described below.

2.1. Literature review

The first step consisted of a comprehensive review of the literature related to the application of systems thinking to the study of the development of bio-based sectors and the transition to the bioeconomy, with the objective of identifying the factors that influence performance in these processes and detecting research gaps. For this purpose, we applied an approach based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method (Figure 2), using different combinations of the keywords "system dynamics", "systems thinking", "bioeconomy", "bio-based economy", "transition", "innovation", and "innovation system" within article titles, keywords, and abstracts in the Scopus database. After several iterations, the searches that yielded a manageable number of relevant results (under 500) were "bio-based economy" AND "transition" (148 results), "system dynamics" AND "innovation system" (116 results), "bioeconomy" AND "transition" AND "factors" (65 results), "systems thinking" AND "innovation system" (60 results), "bioeconomy transition" (39 results), "system dynamics" AND "bioeconomy" (16 results), "systems thinking" AND "bioeconomy" (9 results), "bioeconomy" AND "transition" AND "variables" (8 results), "transition to the bioeconomy" (8 results), "system dynamics" AND "bioeconomy" AND "transition" (3 results), "transition to the bio-based economy" (2 results), "system dynamics" AND "bio-based economy" (2 results), and "systems thinking" AND "innovation system" AND "CLDs" (1 result). The duplicates were then discarded, a qualitative screening of the remaining articles was performed through a review of the abstracts followed by a full text review, and a total of 30 were retained due to their relevance for our study (Allas, 2014; Allena-Ozolina and Bazbauers, 2017; Barisa et al., 2015; Bautista et al., 2019; Bennich et al.,

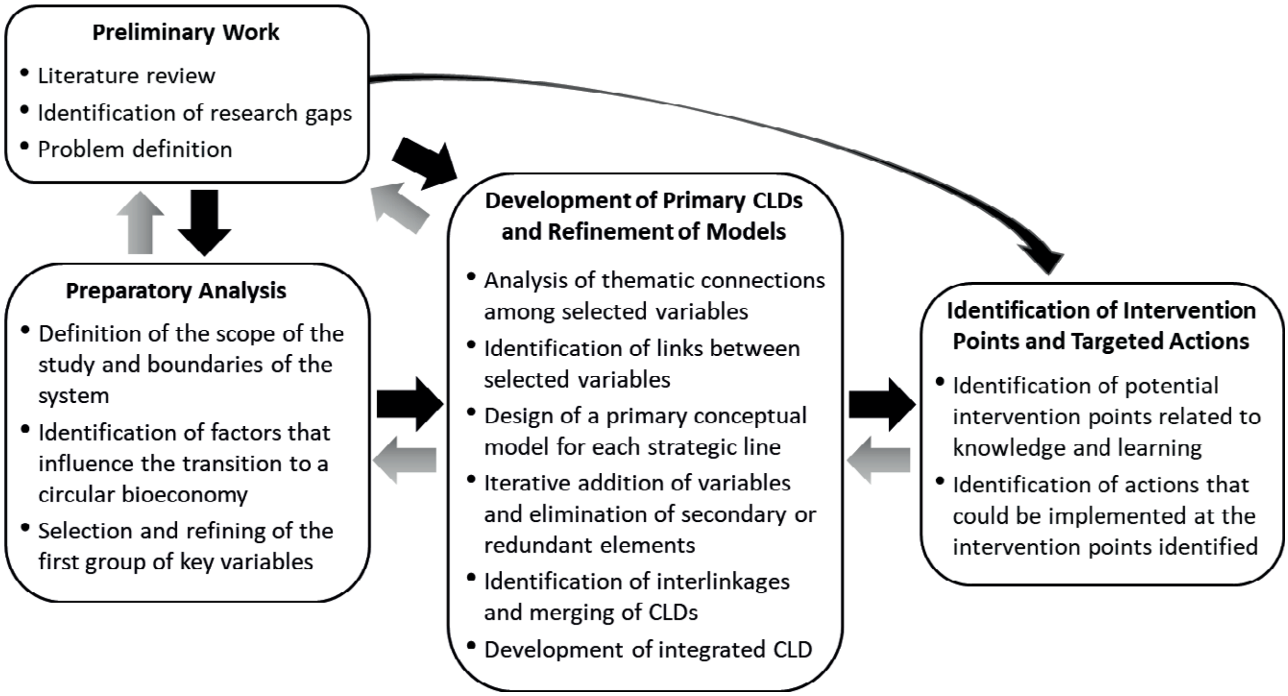

Figure 1. Research methodology flowchart.

2018a, 2018b; Blumberga et al., 2018; Bröring et al., 2020; Candido et al., 2017; Cavicchi, 2020; Chitawo et al., 2018; Galanakis, 2006; Gottinger et al., 2020; Hakim et al., 2016; Jin et al., 2019; Layani et al., 2021; Maldonado, 2012; Milling, 2012; Oriama and Pyka, 2021; Raven and Walrave, 2020; Runge et al., 2017; Samara et al., 2012; Saryazdi and Poursarrajian, 2021; Sixt et al., 2018; Stark et al., 2022; Stern et al., 2015; Suprun, 2018; Suprun *et al.*, 2019; Uriona *et al.*, 2012; Uriona and Grobbelaar, 2019). Furthermore, a search of the Scopus database with the keywords "system dynamics" AND "bioeconomy" AND "knowledge" was conducted and yielded merely two results, of which only one was relevant to our study but was focused on the health sector (Oriama and Pyka, 2021). This finding revealed an important research gap and led us to the decision of focusing the second part of our study on the identification of learning- and knowledge-related leverage points.

Concurrently, a review of the literature on the Andalusian bioeconomy and innovation system was conducted applying the same approach and the keywords "Andalusia", "bioeconomy", "bio-based economy" and "innovation system", to gain a perspective of the regional context. A total of five documents were retained after expanding the quest to Google Scholar and the Google search engine as the Scopus database did not yield any relevant result (Agency for Innovation and Development of Andalusia, 2022; Ministry of Agriculture, Fisheries and Rural Development of Andalusia, n.d.; Regional Government of Andalusia, n.d.; Vázquez and Cohard, 2014; Vázquez, 2017).

2.2. Preparatory analysis

Several definitions of circular bioeconomy were found in the literature due to the vast variety of sectors and activities that make up the bio-based economy sector (Bugge et al., 2016; Giampietro, 2019). Therefore, for the purpose of this study, we decided to focus on the Andalusian Circular Bioeconomy Strategy 2030 (ACBS) (Regional Government of Andalusia, 2018) and thus adopt the scope therein used to define the circular bioeconomy, i.e., the primary and agro-industrial production of food for human consumption are not included. Food products are considered a resource for the circular bioeconomy only if they are deemed unsuitable for human consumption due to non-compliance with regulations or loss of quality during their processing.

The ACBS document comprises four strategic lines and four cross-cutting lines of programmes (Figure 3). It was developed by the Government of Andalusia over the course of nearly two years, in a process coordinated by the Regional Ministry of Agriculture, Fisheries and Rural Development that included bilateral meetings with

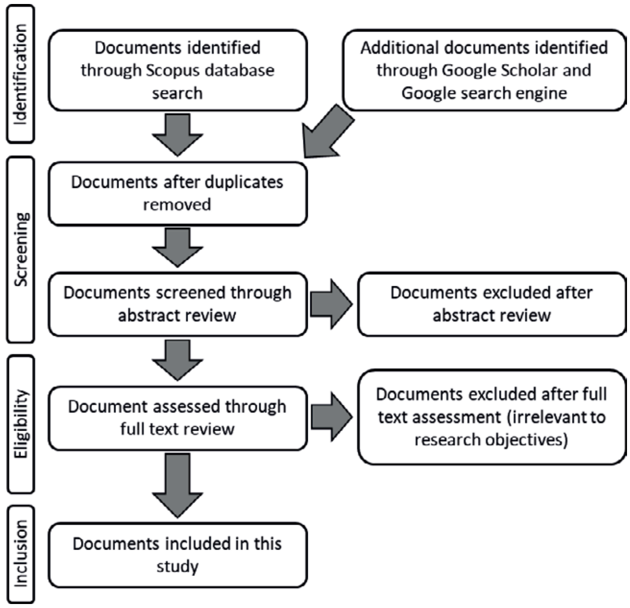

Figure 2. Overview of the document identification, selection and inclusion process followed in this study (Adapted from Page et al., 2021).

various government agencies, the organization of an Andalusian circular bioeconomy forum, and consultations with 53 experts from the private sector, universities, and research organizations. For this reason, it was deemed to contain all the relevant variables and influencing factors required for at least the initial stages of our analysis.

Once the scope was defined, the strategic lines of the ACBS were set as the boundaries of the system for this study and a first group of variables was selected from each one of them, using the 30 articles retained in our literature review as a guiding reference. These were subsequently submitted to further refining based on the Andalusia-related literature and the thematic connections among them was analyzed to further define the boundaries of the system.

2.3. Development of CLDs and refinement of the models

In the next step, the variables selected during the preparatory analysis were used to design a primary conceptual model for each of the four strategic lines, using causal loop diagrams (CLDs) prepared with Vensim PLE software (Ventana Systems, 2022), and links identified in models developed previously for the bio-based sector and other sectoral innovation systems (Allas, 2014; Bennich et al., 2018a, 2018b; Blumberga et al., 2018; Bröring et al., 2020; Candido et al., 2017; Galanakis, 2006; Maldonado, 2012; Milling, 2012; Oriama and Pyka, 2021; Raven and Walrave, 2020; Samara et al., 2012; Saryazdi and Poursarrajian, 2021; Suprun, 2018; Suprun *et al*., 2019; Uriona *et al*., 2012; Uriona and Grobbelaar, 2019).

Subsequently, taking the primary CLDs as the starting point, the models were improved iteratively to portray the relationships among the key variables and factors formulated in the Andalusian strategy, providing a visual understanding of the causal relationships and the feedback loops that shape the reinforcing and balancing forces between the various components of the system. Along this process, several secondary or redundant elements were gradually eliminated to obtain a simple but comprehensive representation of the system with the lowest possible number of elements (Sterman, 2000). The resulting CLDs were subsequently merged into a series of integrated CLDs, to provide an overall view of the system.

2.4. Identification of intervention points and targeted actions

Lastly, the strategic lines and programmes of the ACBS were revisited for a full text analysis of its 17 prescribed measures to identify specific actions related to learning and knowledge that are known for their effectiveness in industrial development and that could be implemented to facilitate the transition to a circular bio-based economy. The actions thus identified were subsequently used to find the appropriate intervention points where their implementation could have meaningful impact (Meadows, 2009).

Throughout the entire process, the literature findings were complemented by the authors' combined experience of over three decades in the analysis, design, and implementation of public policies, strategies and programs for science, technology, innovation, and economic development in both government and the academic sector in North America and the European Union. In addition, preliminary versions of the CLDs and their intervention points were presented for feedback and comments at the ISPIM Innovation Conference 2021 (Berlin, Germany, June 20-23, 2021) and 30 experts at the XIII Agrifood Economics Congress of the Spanish Association of Agri-food Economy (Cartagena, Spain, September 1-3, 2021), which allowed the collection of further contributions that enriched the results.

3. RESULTS

The data gathered from the literature review and analysis of the ACBS led to four conceptual CLDs por-

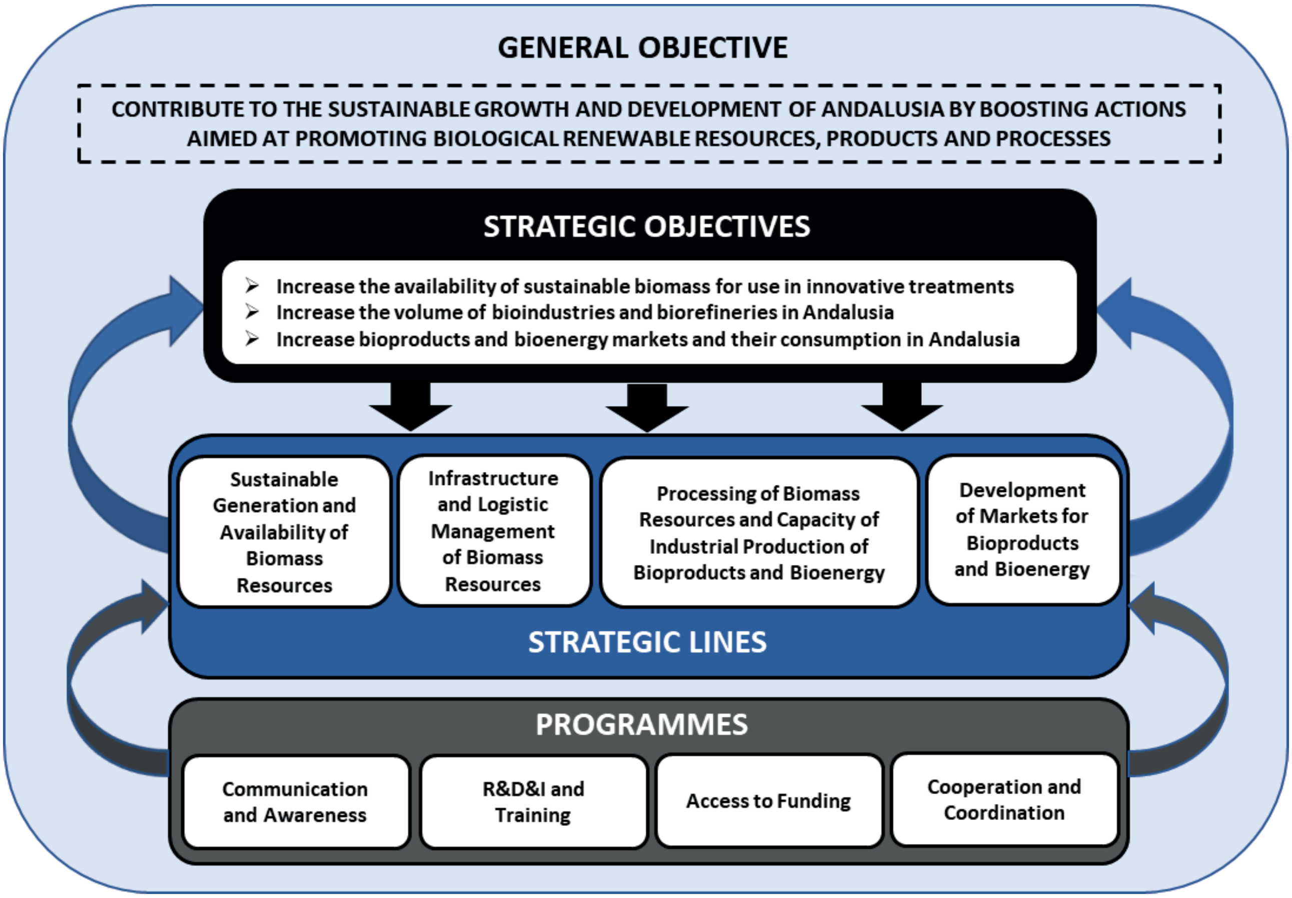

Figure 3. Strategic and instrumental framework of the Andalusian Circular Bioeconomy Strategy 2030 (Adapted from: Regional Government of Andalusia, 2018).

traying the causal relationships among 33 key variables identified from the four strategic lines of the ACBS: (1) sustainable generation and availability of biomass resources, (2) infrastructure and logistics management of biomass resources, (3) processing of biomass resources and capacity of industrial production of bioproducts and bioenergy, and (4) development of markets for bioproducts and bioenergy. Subsequently, after merging them into a series of integrated CLDs, a total of 20 key learning- and knowledge-related interventions points were identified, along with 52 targeted actions that could have meaningful impact on the system.

3.1. Sustainable generation and availability of biomass resources

The first strategic line formulated in the ACBS relates to increasing the availability of biomass resources produced sustainably for their subsequent conversion into bioproducts and bioenergy. During the analysis of the document, several reinforcing feedback loops were identified that would lead to higher "Availability of sustainable biomass resources" (capitalized, Figure 4).

As the main proponent and champion of the regional strategy, government investment in technology and training for sustainable biomass production ("Public investment in technology and training I") drives the development of "Skills in sustainable biomass production" as well as the "Deployment of sustainable technologies for biomass production" both directly (reinforcing feedback loops R1a, R1b, and R1c) and through the enhancement of private investment in these activities (reinforcing feedback loops R2a, R2b, and R2c). All these together trigger an increase in the "Share of land and water used for sustainable biomass production", which in turn leads to a higher "Volume of biomass produced sustainably". The higher "Availability of sustainable biomass resources" thus achieved consequently induces an increase in both the "Use of sustainable biomass in bioindustrial processes" and the "Use of biomass

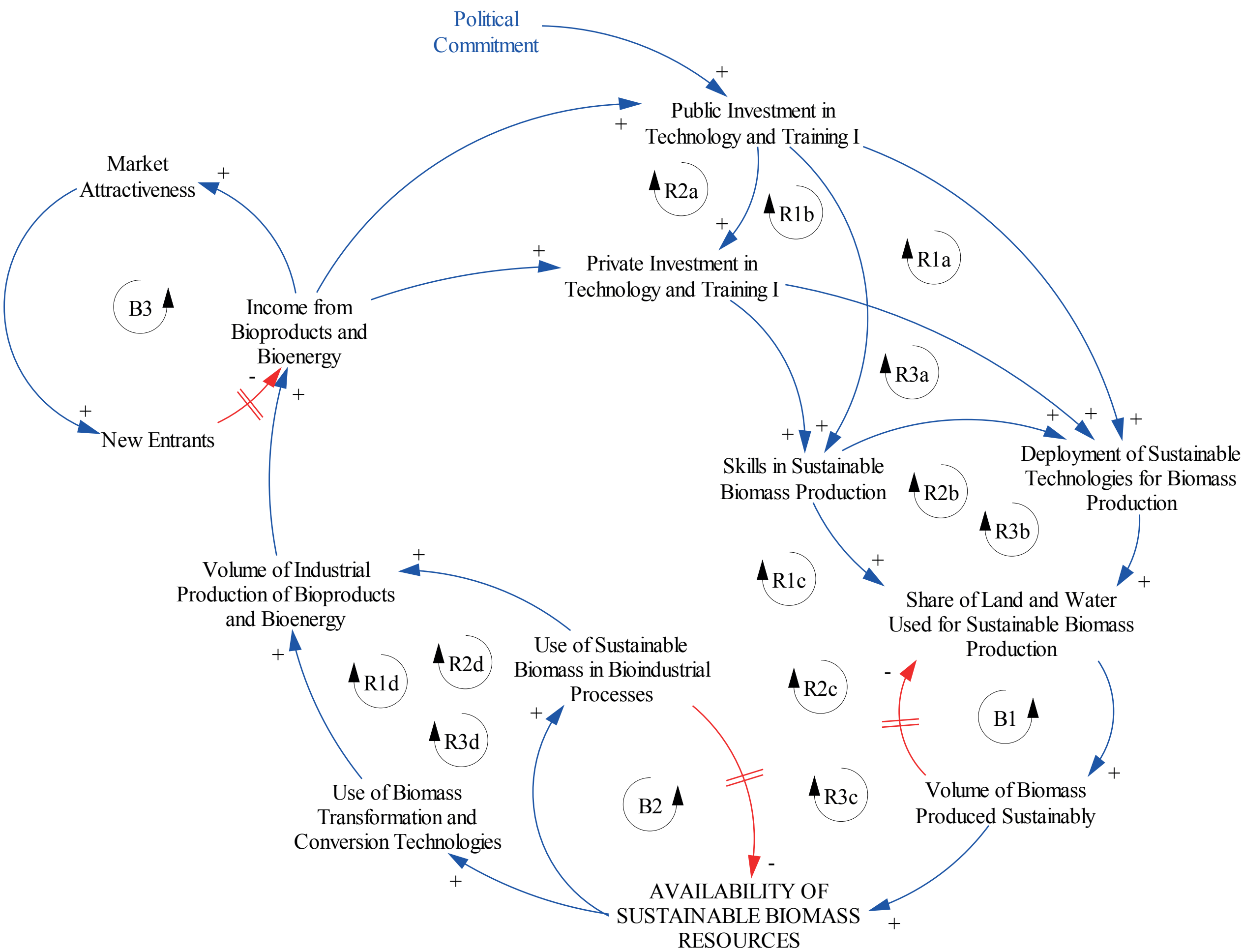

Figure 4. Dynamics suggested to govern the availability of sustainable biomass resources.

transformation and conversion technologies" (reinforcing feedback loops R1d and R2d), resulting in a higher "Volume of industrial production of bioproducts and bioenergy" and increased "Income from bioproducts and bioenergy" (as well as from related services). Lastly, the economic, environmental, and social benefits that accrue from these activities close the loop by prompting more public and private investment in technology and training for sustainable biomass production. The private sector also can promote these cycles (reinforcing feedback loops R3a, R3b, R3c, and R3d), but the impact on the system is lower if it does it alone.

Three balancing feedback loops were identified. Water and land of good quality are often limited resources, but this condition is exacerbated in Andalusia due to the region's geographic characteristics. Therefore, the more resources are used to produce biomass for bioproducts and bioenergy, the lower the potential to further expand sustainable biomass production for these purposes (delayed balancing feedback B1). Likewise, the more biomass is used in bioindustrial processes, the lower the potential to further expand these activities (delayed balancing feedback B2). And as new entrants are attracted to the region's circular bioeconomy industry due to increasing income from bioproducts and bioenergy, higher competition for resources would eventually become a limiting factor (delayed balancing feedback B3).

3.2. Infrastructure and logistic management of biomass resources

The second strategic line described in the ACBS relates to optimizing the management and distribution of biomass resources from the points where they are generated to the bioindustries that use them as inputs. Several reinforcing feedback loops were identified during

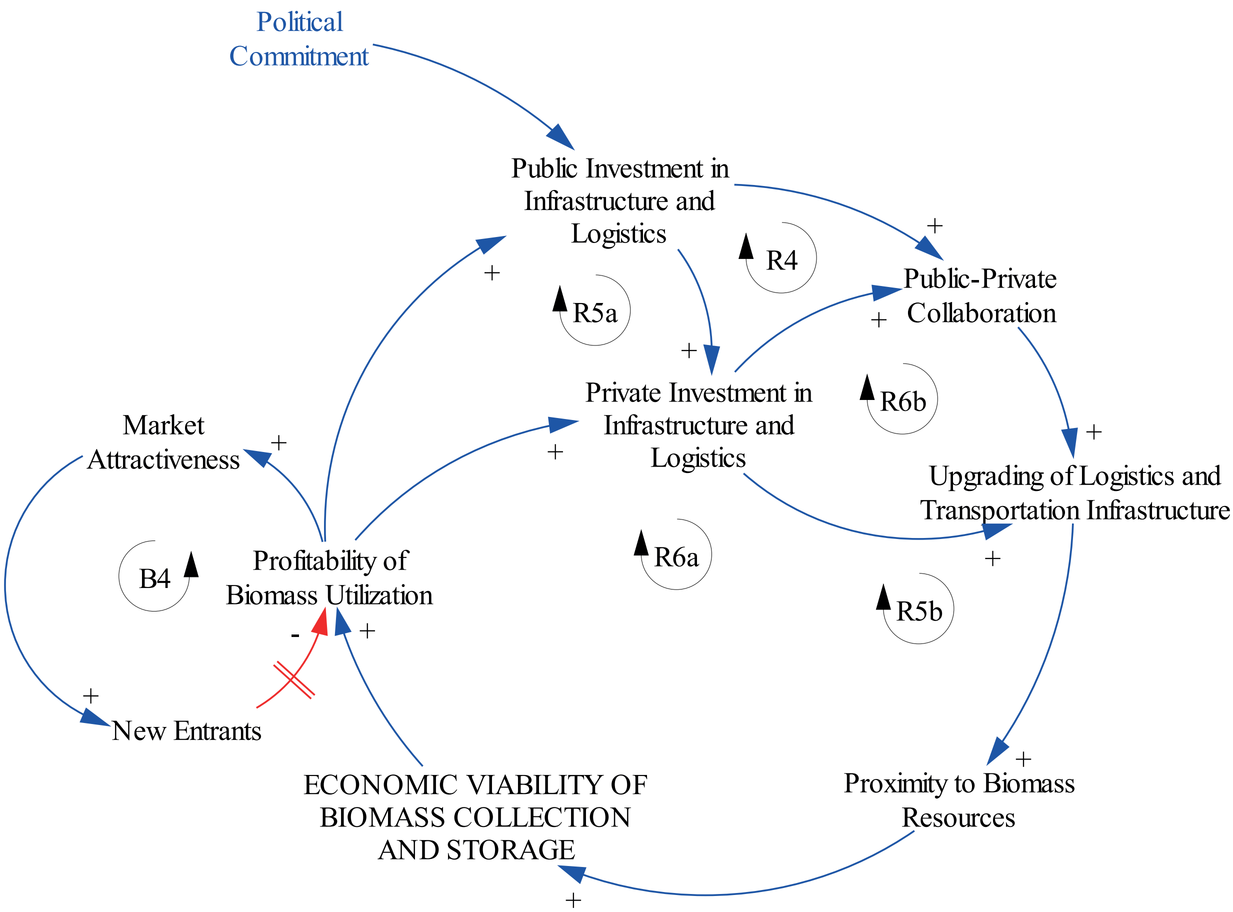

Figure 5. Causal loop diagram displaying the dynamics hypothesized to govern the economic viability of biomass collection, transportation, and storage.

the analysis that would lead to higher "Economic viability of biomass collection and storage" (capitalized, Figure 5).

While private investment alone can have a positive impact on the "Logistics and transportation infrastructure" available to the sector (reinforcing feedback loop R6a), public investment is a key factor for the success of this strategic line of the ACBS through several ways, which include direct contributions to "Public-private collaboration" initiatives (reinforcing feedback loop R4) as well as financial support and market signals that encourage private investment (reinforcing feedback loops R5a, R5b, and R6b).

"Public investment in infrastructure and logistics" plays an important role not only on the construction and maintenance of infrastructure and facilities but is seen as essential to improve knowledge about the volume and location of the biomass resources – through the development of inventories of the biomass available for bioindustrial processes in the region. On the other hand, as agricultural and agro-industrial residues and by-products are typically spread across vast areas (for example, biomass from pruning of olive crops is spread throughout 2.5 million hectares of plantations across the entire region of Andalusia), "Public-private collaboration" is deemed necessary to improve the "Economic viability of biomass collection and storage" by "Upgrading the Logistics and Transportation Infrastructure" and increasing the "Proximity to biomass resources", which in turn would contribute to boost the "Profitability of biomass utilization". Lastly, as the first results of this collaborative work become evident, the model would be replicated across the region through more public and private investment in logistics and transportation infrastructure.

And as in the previous model, the attractiveness of the growing market would attract new entrants which, over time, would have a negative impact on returns because of higher competition for the limited resources available (delayed balancing feedback B4).

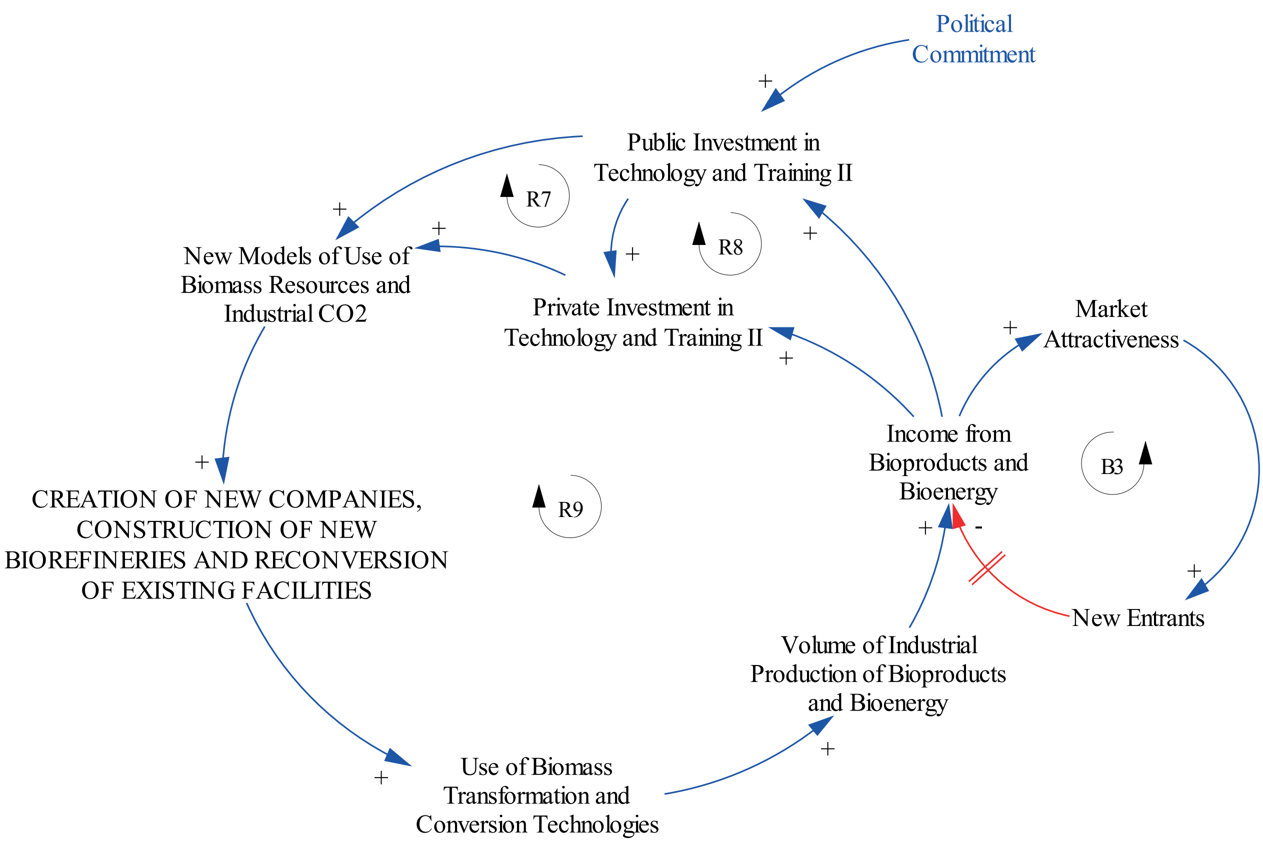

Figure 6. Dynamics suggested to govern the development of industrial capacity to process biomass resources and produce bioproducts and bioenergy.

3.3. Processing of biomass resources and capacity of industrial production of bioproducts and bioenergy

The third strategic line defined in the ACBS comprises actions to support the development of a bio-based industry that optimizes the use of biomass resources in Andalusia, especially through integrated biorefineries. As in the previous cases, several reinforcing feedback loops were identified (Figure 6).

According to this model, investments in technology and training by the public and private sector would lead to the development of "New models of use of biomass resources and industrial CO_2". As synergies are achieved, new companies would be created, new biorefineries would be built, and existing facilities would be reconverted to increase the "Industrial use of transformation and conversion technologies" and expand the "Volume of industrial production of bioproducts and bioenergy". As in the previous models, private investment alone can generate positive results (reinforcing feedback loop R9), but public sector involvement can potentiate the system through direct investments, financial support, and positive market signals (reinforcing feedback loops R7 and R8). The income thus generated from bioproducts and bioenergy (as well as from related services) would produce economic, environmental, and social benefits that would in turn encourage more public and private "Investment in technology and training" for biomass transformation and conversion. However, as in the previous models, once the biomass processing sector reaches a critical mass, its attractiveness would encourage the entry of new players up to a point where the competition for resources would become a limiting factor (delayed balancing feedback B3).

3.4. Development of markets for bioproducts and bioenergy

The fourth and last strategic line formulated in the ACBS consists of actions aimed at consolidating the markets that already exist in Andalusia while promoting and supporting the development of national and international value chains for bioproducts and bioenergy. As described in Figure 7, several reinforcing feedback loops

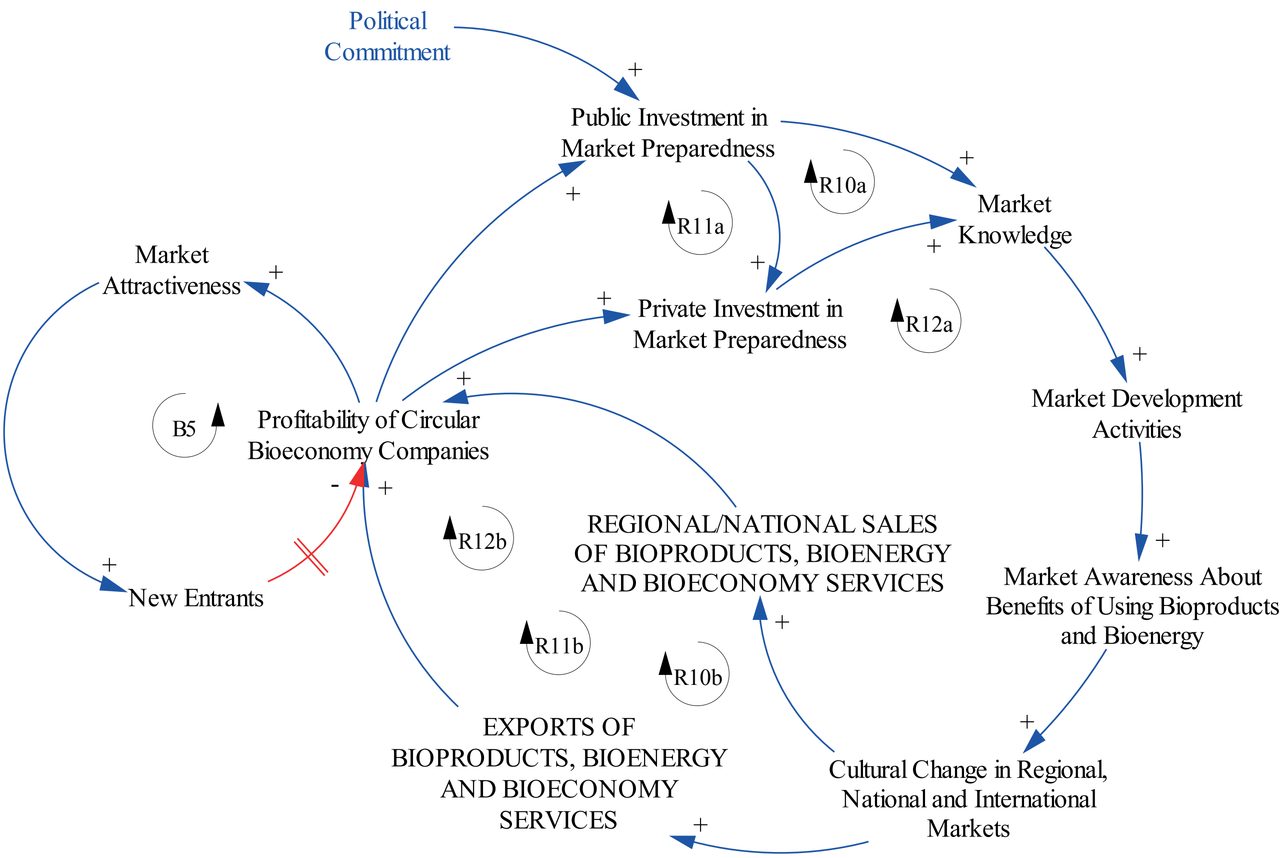

Figure 7. Causal loop diagram displaying the dynamics hypothesized to govern the development of markets for bioproducts and bioenergy.

were identified that would lead to higher sales of bioproducts, bioenergy, and related bioeconomy services.

Once again, synergistic "Investments in market preparedness" by the public and private sector would lead to enhancements in the collective "Market knowledge" about opportunities for bioproducts, bioenergy, and bioeconomy-related services. With this valuable information at hand, both government planning and corporate business plans would be upgraded to support "Market development activities" aimed at increasing "Market awareness about the benefits of using bioproducts and bioenergy" and triggering the "Cultural change in regional, national and international markets" that is needed to switch consumption towards products and energy obtained from sustainable biomass resources. Lastly, higher sales of bioproducts, bioenergy, and related bioeconomy services to local, regional, and national customers (reinforcing feedback loops R10a, R11a, and R12a), as well as in international markets (reinforcing feedback loops R10b, R11b, and R12b) would close the loop by increasing the "Profitability of circular bioeconomy companies", which would in turn stimulate more public and private investments in market development activities. As in the previous strategic lines, the finite availability of biomass resources would eventually become a limiting factor as the attractiveness of the new markets leads to the entry of new market players (delayed balancing feedback B5).

3.5. Combined causal loop diagrams and key intervention points

While the individual CLDs in Figures 4 to 7 depict the dynamics of different dimensions of the system, some interlinkages were identified. Figures 8 and 9 display combined CLDs, highlighting the proposed cross-dimension interlinkages, as well as a total of 20 key learning- and knowledge-related intervention points identified from the ACBS and the literature where targeted actions could have meaningful impact. These were subsequently merged into an integrated CLD (Figure 10) for the ACBS.

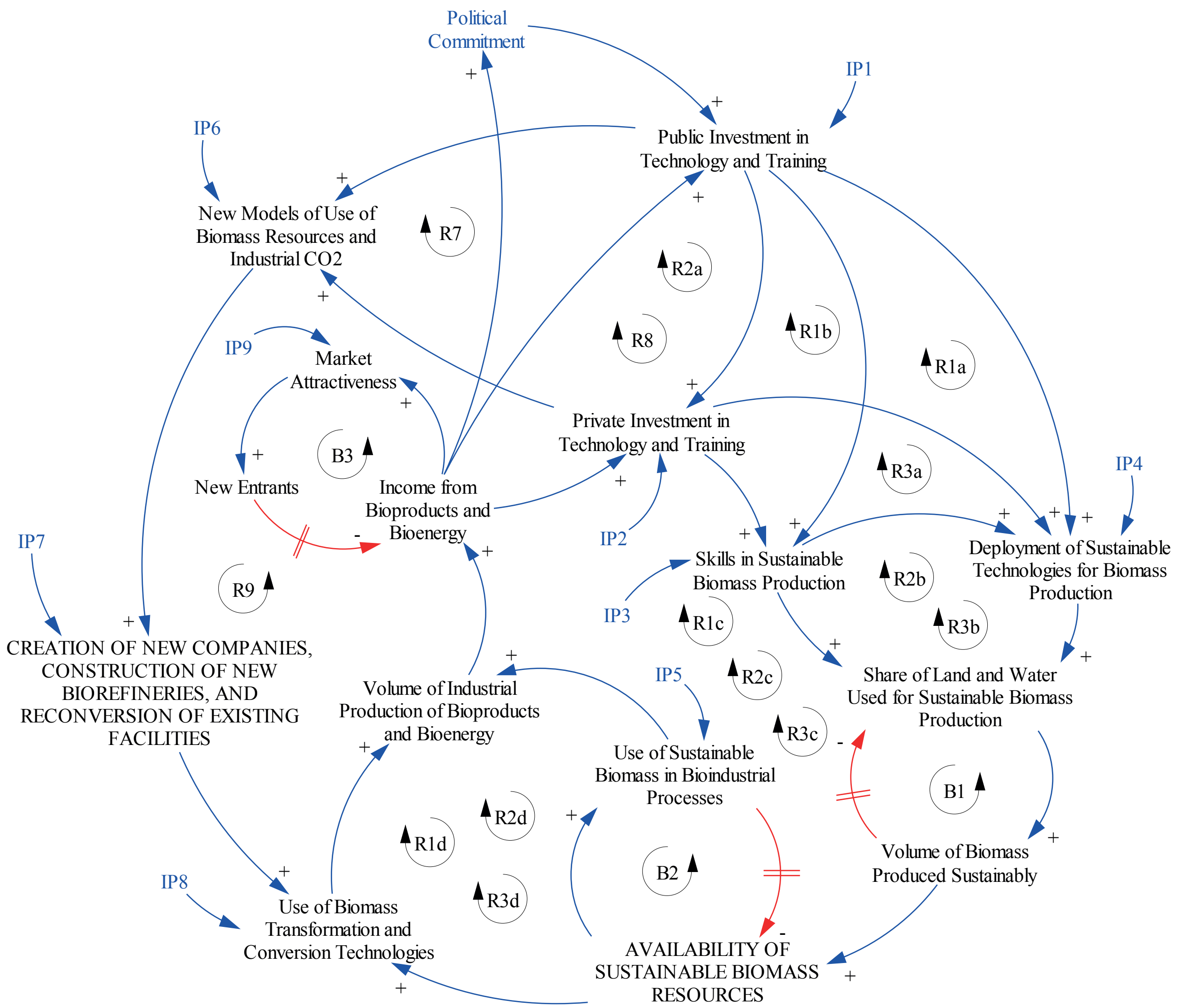

Figure 8. Dynamics suggested to govern the sustainable generation of biomass resources as well as the development of industrial capacity to process biomass resources and obtain bioproducts and bioenergy.

3.5.1. Sustainable generation of biomass resources; development of industrial capacity to process biomass resources and generate bioproducts and bioenergy

An analysis of both the ACBS and Figures 4 to 7 reveals that the strategic lines 1 and 3 of the document have some common variables related to technology and training and, as a result, their respective CLDs merge as shown in Figure 8.

A subsequent evaluation led to the identification of 9 key learning- and knowledge-related points susceptible of intervention. Of these, four (IP1, IP2, IP3, and IP4) are related to public and private investment in technology and training, the development of skills, and the deployment of sustainable technologies, all of which together would lead to an increase of the volume of biomass produced sustainably. Subsequently, activities designed to enhance the sharing of knowledge regarding the use of biomass in bioindustrial processes (IP5) would lead to an increase in the volume of industrial production of bioproducts and bioenergy, which is concurrently potentiated by actions designed to promote learning about new models of use of biomass resources and industrial CO_2 (IP6). Lastly, as new companies are created, new biorefineries are built, and existing facilities are reconverted, the Andalusian circular bioeconomy would benefit significantly from greater access to the growing stock of knowledge about technologies for biomass transformation and conversion, the various types of bioproducts and bioenergy generated from these sources, and the rising income from these activities (IP7, IP8, and IP9). Above all of these, given that the circular bioeconomy is an emerging sector that will require ongoing government support for some time, political commitment to public investments in technology and training is key for its success. Table 1 contains a list of targeted learning- and knowledge-related actions identified from the ACBS and the authors' analysis that could be implemented with meaningful impact at these intervention points.

3.5.2. Economic viability of biomass collection and storage; development of markets for bioproducts and bioenergy

As for the strategic lines 2 and 4 of the ACBS, negligible overlap was observed among them and with the others, as shown in Figure 9.

Of the 11 learning- and knowledge-related intervention points identified for these two strategic lines of the ACBS, four (IP10 to IP13) are related to increasing the economic viability of biomass collection and storage, whereas six (IP14 to IP19) are linked to the commercialization of bioproducts, bioenergy, and bioeconomy services. Interestingly, while a significant part of the activities contained in Figure 8 involve science, technology, and innovation (STI)-based learning processes, actions aimed at building structures and relationships to enhance the doing, using, and interacting (DUI) mode of learning (Jensen et al., 2007; Thomä, 2017) are likely to have higher impact in these strategic lines. Lastly, one intervention point (IP20) was shared by both strategic lines and as noted in the previous figure, political commitment plays a pivotal role due to the emerging nature of the circular bioeconomy sector. Table 2 contains a list of targeted learning- and knowledge-related targeted actions identified from the ACBS and the literature that could be implemented with meaningful impact at these intervention points.

3.6. Integrated causal loop diagram

Figure 10 displays an integrated CLD, highlighting the proposed cross-dimension interlinkages, as well as the central role played by government in the development of this emerging sector of the economy.

4. DISCUSSION

The application of the system dynamics approach to the analysis of Andalusia's circular bioeconomy provides important insights into the complexity of the system due to the existence of non-linear processes, multiple feedback loops, and time delays. Likewise, the models generated in this study provide tools for a better understanding of the potential impact that learning- and knowledge-related interventions by governments and other actors could have on different parts of the development of the circular bioeconomy.

4.1. Learning, knowledge, and innovation

A strong innovation ecosystem based on a balance between science and technology push and market and social pull will play a leading role in the realization of the potential presented by the circular bioeconomy and, in realizing this potential, it will be fundamental to keep in mind that an important aspect of the innovation process is its heterogeneity across sectors, industries, and regions. In this regard, assessing and measuring the underlying processes of learning and knowledge accumulation for innovation has been an ongoing challenge for decades (Abramovitz, 1956; Dosi, 1982; Romer, 1990; Solow, 1957). This has had important repercussions for technology, innovation, and economic development policymaking, which has strongly relied on a linear R&D-based innovation model. Nevertheless, the literature on the topic is increasingly recognizing external knowledge sources as key elements of the innovation process (Doloreux et al., 2020; Fitjar and Rodríguez-Pose, 2013; Isaksen and Nilsson, 2013; Jensen et al., 2007; Santner, 2018) as well as the systemic nature of the innovation systems framework (Uriona and Grobbelaar, 2019).

One of the most valuable efforts to understand how the process of learning and innovating can differ in firms is the work of Jensen et al. (2007), that distinguishes two fundamental forms: the Science, Technology, and Innovation (STI) mode, which focuses on the production and use of codified scientific and technical knowledge; and the Doing, Using, and Interacting (DUI) mode, which focuses on experience-based know-how and informal interactive learning. Since the proposal of this taxonomy, several studies have explored the extent to which these two modes of innovation can be observed in different economic sectors, providing insights into their links with firm innovativeness on the one hand (e.g. Apanasovich et al., 2016; Aslesen and Pettersen, 2017; Doloreux et al., 2020; Figueiredo and Piana, 2021; González-Pernía et al., 2015; Isaksen and Karlsen, 2010; Parrilli and Elola, 2012;

Table 1. Proposed learning- and knowledge-related actions to boost the sustainable generation of biomass resources and enhance the development of industrial capacity to process biomass resources and obtain bioproducts and bioenergy.

Intervention Point	Variable	Proposed Action	Related ACBS Actions
IP1	Public Investment in Technology and Training	· Promote knowledge among public sector staff and policy makers regarding the strengths, needs, gaps, opportunities, barriers, and risks faced by the bioeconomy to improve the quality of public investment decisions in technology and training.	(1.1.1) (1.1.2) (1.2.1) (1.2.2) (2.1.1) (2.1.2) (3.1.1) (3.1.2) (B.1.1) (B.1.3) (B.3.1) (D.1.2) (D.2.1)
		· Foster knowledge among public sector staff and policy makers about alternative ways of collaborative financing as well as about the role that governments can play as early adopters of innovative solutions through instruments such as public procurement of innovation (PPI).	(B.1.2) (C.1.2)
IP2	Private Investment in Technology and Training	· Promote knowledge among the private sector regarding the strengths, needs, gaps, opportunities, barriers, and risks faced by the bioeconomy to improve the quality of private investment decisions in technology and training.	(1.1.1) (1.1.2) (1.2.1) (1.2.2) (2.1.1) (2.1.2) (3.1.1) (3.1.2) (B.1.1) (B.1.3) (B.3.1) (D.1.2) (D.2.1)
		· Promote knowledge among the private sector about financial instruments available for the circular bioeconomy.	(C.1.1) (C.1.2)
		· Upgrade management skills in the private sector to increase the absorptive capacity of companies to receive public funding and improve the quality of their investment decisions in technology and training.	(1.2.1) (3.1.2) (3.2.1) (B.3.1)
		· Foster initiatives to disseminate knowledge among local, national, and foreign investors about the region's competitive advantage in the bioeconomy and specific investment opportunities in R&D, technology, and training.	(1.1.1) (2.1.1) (3.2.1) (3.2.2) (C.2.1) (C.2.2)
IP3	Skills in Sustainable Biomass Production	· Implement mechanisms and tools to increase the interaction between all levels of the education system and the actors involved in the generation of biomass to promote technical advice, education and training in matters related to sustainable practices. Adjust the offer to the needs of the market.	(1.2.1) (1.2.2) (B.1.2) (B.1.4) (B.1.5) (B.2.1) (B.3.1) (B.3.2)
		· Develop guidelines and case studies to disseminate knowledge about practices that have shown good results for the sustainability of the generation of biomass resources.	(1.2.1) (1.2.2) (B.1.3) (B.1.4)
IP4	Deployment of Sustainable Technologies for Biomass Production	· Implement mechanisms and tools to increase the interaction between all levels of the education system and the actors involved in the generation of biomass to promote technical advice, education and training in matters related to sustainable technologies. Adjust the offer to the needs of the market.	(1.2.1) (1.2.2) (B.1.2) (B.1.4) (B.1.5) (B.2.1) (B.3.1) (B.3.2)
		· Prepare technology surveillance reports to disseminate knowledge about current and upcoming technologies available for sustainable biomass production.	(1.2.1) (1.2.2) (B.1.3) (B.1.4)
		· Develop guidelines and case studies to disseminate knowledge about technology solutions that have shown good results for the sustainability of the generation of biomass resources.	(1.2.1) (1.2.2) (B.1.3) (B.1.4)
IP5	Use of Sustainable Biomass in Bioindustrial Processes	· Develop and regularly update an inventory of biomass resources in the region to disseminate knowledge about the types and volumes available, their physical and chemical characteristics, their geographic location, and the distribution of their availability over time (seasonality).	(1.1.1)
		· Develop and regularly update a georeferenced inventory of potential users of biomass resources.	(2.1.1)

Intervention Point	Variable	Proposed Action	Related ACBS Actions
IP6	New Models of Use of Biomass Resources and Industrial CO_2	· Foster the incorporation of technical and business skills into the knowledge of people who work in bioindustries to improve the sustainability of companies and increase the addition of value to the region's biomass resources.	(3.1.1) (3.1.2) (B.1.2) (B.1.3) (B.1.4) (B.1.5)
		· Promote collaboration and the generation of synergies within the bioeconomy sector and with other industries to advance new models of use of biomass resource flows and industrial sources of CO_2.	(3.1.3) (B.1.4) (B.1.5) (B.2.1) (B.2.2)
		· Establish and support business clusters, incubators, accelerators, and mentoring programs to promote technology and knowledge transfer among the different innovation system actors interested in the bioeconomy.	(B.1.2) (B.1.5) (D.1.1)
		· Develop guidelines and case studies based on regional, national, and international success stories to disseminate knowledge about new models of use of biomass resources and industrial CO_2.	(3.1.2) (B.1.3) (B.1.4)
IP7	Creation of New Companies, Construction of New Biorefineries, and Reconversion of Existing Facilities	· Leverage the knowledge and experience acquired in sectors such as the biodiesel industry to promote the development of higher value-adding activities and the conversion of existing facilities to biorefineries.	(3.2.2)
		· Develop guidelines and case studies based on regional, national, and international success stories to disseminate knowledge about the planning and implementation of bioindustries and biorefineries.	(3.1.2) (B.1.3) (B.1.4)
IP8	Use of Biomass Transformation and Conversion Technologies	· Implement mechanisms and tools to increase the interaction between all levels of the education system and the bio-based industry to promote technical advice, education and training in matters related to the use of technologies for sustainable biomass transformation and conversion. Adjust the offer to the needs of the market.	(3.1.1) (3.1.2) (B.1.2) (B.1.4) (B.1.5) (B.2.1) (B.3.1) (B.3.2)
		· Foster collaboration and the establishment of regional, national, and international alliances and multi-actor platforms to facilitate the transfer of knowledge and the adoption of sustainable technologies generated by the R&D and innovation system.	(3.1.3) (B.1.4) (B.1.5) (B.2.1) (B.2.2) (D.1.1)
		· Promote the establishment of technology sandboxes and pilot plants for process development and scale-up of sustainable bio-based products and processes.	(B.1.2) (Authors' analysis)
		· Prepare technology surveillance reports to disseminate knowledge about current and upcoming technologies for sustainable biomass transformation and conversion.	(3.1.1) (B.1.3) (B.1.4)
		· Develop guidelines and case studies to disseminate knowledge about technology solutions that have shown good results for the sustainable transformation and conversion of biomass.	(3.1.1) (3.1.2) (B.1.3) (B.1.4)
IP9	Market Attractiveness	· Develop a portfolio of successful projects, technological innovations, business initiatives, and business models, for each of the links in the value chains associated with the bioeconomy to expand knowledge about the opportunities presented by the bio-based economy across various stakeholder groups.	(3.1.1) (3.1.2) (B.1.3) (B.1.4)

Santner, 2018; Thomä, 2017) and with the geography of innovation on the other (Fitjar and Rodríguez-Pose, 2013; Parrilli and Alcalde-Heras, 2016).

Overall, the learning- and knowledge-related actions identified in this study to accelerate Andalusia's transition from a linear bio-based economy to a sustainable circular bioeconomy support the view that an innovation system that encourages a combination of STI and DUI activities will have the greatest potential of success as each company will choose the learning mode that best suits its scientific, technological, and geographic context (Fitjar and Rodriguez-Pose, 2013; Parrilli and Alcalde-Heras, 2016). Thus, when confronted with the current scenario, the cause-effect relationships and causal cycles herein described suggest that the Andalusian innovation system needs greater collaboration and coordination along and across the triple helix to support the development, commercialization, and diffusion of

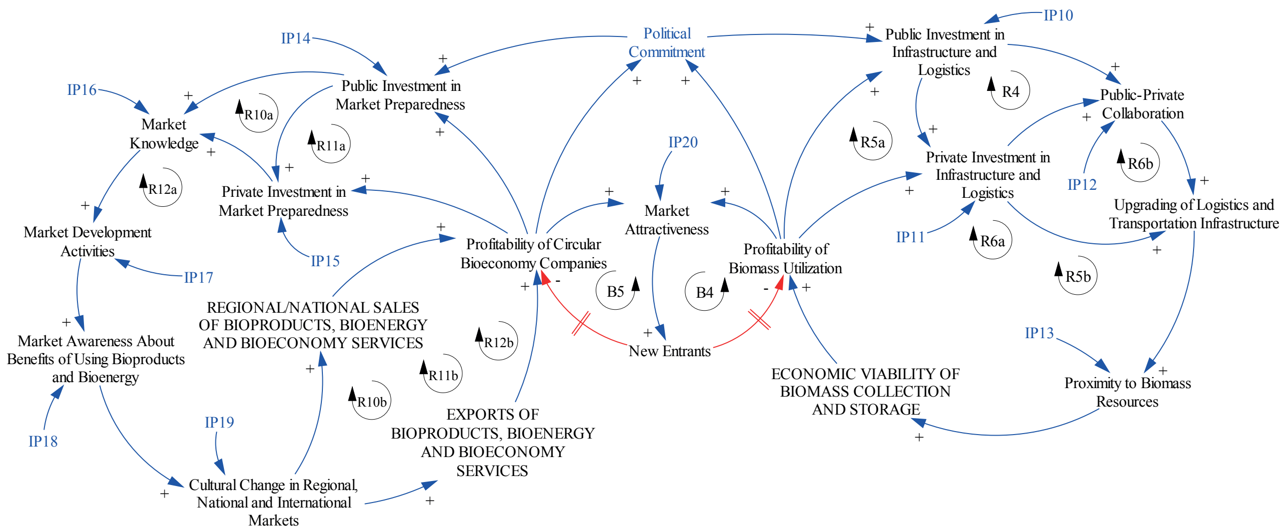

Figure 9. Causal loop diagram displaying the dynamics hypothesized to govern the economic viability of biomass collection and storage as well as development of markets for bioproducts and bioenergy.

innovative solutions, all of which are necessary for the development of critical mass in the region's circular bioeconomy.

4.2. The role of government

One of the main challenges faced by transition regions such as Andalusia in their attempt to close the gap with developed regions is to find the right balance between technological innovation and technological imitation as well as the choice of technologies to be developed and imitated (Atkinson and Stiglitz, 1969; Basu and Weil, 1998; Lin, 2003).

For less developed and transition regions, fulfilling the promise of faster economic growth through technological imitation is not an easy task. Studies on technology diffusion have shown that the process of closing the technology gap requires a significant amount of effort and institution building, and that in this process less developed and transition regions generally face larger requirements for capital and other advanced factors than developed regions. Thus, in addition to the licensing fees, regions that adopt technologies from leading regions need to incur expenses in the retraining of human capital, organizational restructuring, and so on (Stoneman, 1983). Furthermore, as the characteristics of new technologies are strongly influenced by the business environments in which they are developed, large differences between regions can represent serious barriers for their transfer. Among the factors that have been suggested to play a crucial role in a region's ability to import technology are its political, commercial, industrial, and financial institutions, as well as national characteristics such as market size and the relative supply of factors of production (Abramovitz, 1986; Caselli and Coleman, 2001; Chen and Wang, 2021; Keller, 2004). Technological change is therefore the combined result of innovation and learning activities within domestic organizations, and of the interaction among them and with their environment. It thus becomes obvious that firms, with their different combinations of intrinsic competencies and business strategies, are key players in this process (Fagerberg, 1994).

As the costs of adoption of new technologies tend to exceed the benefits obtained, these are often not adopted as soon as they become public (Stoneman, 1983). The process of technological diffusion then occurs gradually, with a few firms adopting the technology first and the others following in a process that can take more than a decade or even stop before its completion (Detragiache, 1998). Remarkably, as the followers have the possibility of copying the adaptive efforts of the pioneers and, at the same time, have access to more skilled labor trained by the early adopters, the costs of adoption tend to decrease as more firms import the technology. Based on the premise that early adopters create positive externalities for the followers, Detragiache (1998) proposed that, once technology adoption starts, less developed regions tend to converge to the level of developed regions as more firms adopt the new technology. Accordingly, different degrees of economic convergence among regions are explained by differences in the rate of diffusion of

Table 2. Proposed learning- and knowledge-related actions to potentiate the economic viability of biomass collection and storage and the development of markets for bioproducts and bioenergy.

Intervention Point	Variable	Proposed Actions	Related ACBS Actions
IP10	Public Investment in Infrastructure and Logistics	· Improve knowledge about biomass resources and industrial sources of CO_2 among public sector staff and policy makers in terms of those factors that determine their logistics, as well as about the infrastructure that is required to ensure the supply of biomass to operators, users, and bioindustries.	(1.1.1) (1.1.2) (2.1.1) (2.1.2) (2.2.1) (2.2.2) (B.1.3) (B.3.1) (D.1.2) (D.2.1)
		· Promote knowledge among public sector staff and policy makers about potential users of biomass resources and infrastructure gaps in the region.	(2.1.1)
		· Foster knowledge among public sector staff and policy makers about alternative ways of collaborative financing and public-private partnerships (PPP).	(C.1.2)
IP11	Private Investment in Infrastructure and Logistics	· Upgrade technical and management skills in the private sector to increase the absorptive capacity of companies to receive public funding and improve the quality of their investment decisions in infrastructure and logistics for biomass collection, transportation, pretreatment, and storage.	(2.1.2) (3.1.2) (B.3.1)
		· Promote knowledge among the private sector about financial instruments available for the circular bioeconomy.	(C.1.1) (C.1.2)
		· Promote knowledge within the private sector about alternative ways of collaborative financing and public-private partnerships (PPP).	(C.1.2)
		· Foster initiatives to disseminate knowledge among local, national, and foreign investors about the region's competitive advantage in the bioeconomy and specific investment opportunities in infrastructure and logistics for biomass collection, transportation, pretreatment, and storage.	(1.1.1) (2.1.1) (2.2.1) (C.2.1) (C.2.2)
IP12	Public-Private Collaboration	· Develop and regularly update an inventory of biomass resources in the region to improve public and private sector knowledge about the types and volumes available, their physical and chemical characteristics, their geographic location, and the distribution of their availability over time (seasonality).	(1.1.1)
		· Improve public and private sector knowledge about both the infrastructure needed and available for the collection, transportation, pretreatment, and storage of the different types of biomass resources.	(2.1.2)
		· Develop and regularly update a georeferenced inventory of potential users of biomass resources.	(2.1.1)
		· Develop guidelines and case studies to improve public and private sector knowledge regarding best practices in public-private collaboration and about current and upcoming solutions for collection, storage, pretreatment, and transportation of biomass resources.	(2.1.2) (B.1.3) (B.1.4)
IP13	Proximity to Biomass Resources	· Promote the transfer of knowledge and the adoption of technologies associated with bioenergy, bioindustries, and small-scale biorefineries established around new local value chains.	(1.1.1) (3.1.1) (3.1.2) (3.1.3) (3.2.1) (3.2.2) (B.1.4) (B.1.5)
IP14	Public Investment in Market Preparedness	· Improve knowledge among public sector staff and policy makers regarding the needs and gaps faced by the bio-based sector in matters related to market preparedness.	(B.3.1) (B.3.2)
IP15	Private Investment in Market Preparedness	· Promote knowledge among the private sector about financial instruments available for the circular bioeconomy.	(C.1.1) (C.1.2)
		· Upgrade management skills in the private sector to increase the absorptive capacity of companies to receive public funding and improve the quality of their investment decisions in market preparedness.	(B.3.1) (B.3.2)

Intervention Point	Variable	Proposed Actions	Related ACBS Actions
IP16	Market Knowledge	· Carry out and disseminate market studies and feasibility analyses to determine supply and demand, prices, and distribution channels for bioproducts, bioenergy and services linked to the circular bioeconomy.	(4.1.1)
		· Prepare, regularly update, and disseminate prospective studies on consumption trends and new uses of bioproducts and bioenergy, as well as analyses of areas and/or sectors where there is potential for the introduction of bio-based products in their value chains.	(4.1.2)
		· Foster interaction and knowledge exchange among bio-based companies and with actors of other industry sectors. Facilitate communication and cooperation among the different agents, especially with the nonrenewable sector, to promote the identification of potential synergies.	(3.1.3) (4.1.2) (B.1.5) (B.2.1) (B.2.2)
IP17	Market Development Activities	· Foster knowledge exchange among bio-based companies and with actors of other industry sectors to identify potential synergies and promote cooperation.	(B.1.5) (B.2.1) (B.2.2)
		· Promote knowledge among public sector staff and policy makers about the role that governments can play as early adopters of innovative solutions through instruments such as public procurement of innovation (PPI).	(B.1.2) (C.1.2)
		· Upgrade international business skills in the private sector to increase the quality of lead generation and conversion in foreign markets.	(B.3.1) (B.3.2) (Authors' analysis)
		· Monitor the evolution of the different links that make up the value chains of bioproducts and bioenergy (supply of raw materials, production, and commercialization) and promote knowledge exchange across the bio-based sector to improve efficiencies and ensure its ability to meet market demand in the medium and long term.	(3.1.3) (B.1.5) (B.2.1) (B.2.2) (D.1.1) (D.1.2) (D.3.2)
IP18	Market Awareness About Benefits of Using Bioproducts and Bioenergy	· Foster knowledge exchange between the bio-based industry and actors of other sectors of the economy and civil society (such as consumer associations) to promote the differentiating features and added value of bioproducts and bioenergy as well as the positive externalities of the bioeconomy.	(4.2.1) (4.2.2) (A.1.1) (A.1.2)
		· Promote the creation of certification and traceability protocols for bioproducts and bioenergy as tools for knowledge transfer across the bioeconomy and to actors of other economic sectors and civil society.	(4.2.1) (A.1.2)
IP19	Cultural Change in Regional, National and International Markets	· Improve knowledge and business training of public service staff and policy makers in matters related to the bioeconomy, its positive externalities, and the use of assessment tools and instruments such as life cycle analysis and the measurement of the carbon and water footprint of entire value chains.	(4.2.2) (A.1.1) (A.1.2) (B.3.1)
		· Improve knowledge and skills of bio-based companies in matters of full cycle sustainability and the efficient use of all the resources destined for the manufacture of their bioproducts or bioenergy, or for the services that they provide. Promote the use of assessment tools and instruments such as life cycle analysis and the measurement of the carbon and water footprint of their entire value chains.	(4.2.2) (B.3.1)
		· Upgrade the absorptive capacity of the regional economy and society through the introduction of the bioeconomy in the contents of compulsory primary and secondary education, post-compulsory (high school and intermediate vocational training) and higher education (university, continuing education, and advanced vocational training).	(B.3.1) (B.3.2)
		· Implement behavioral science (nudging) tools to promote learning and improve decisions about the sustainable use of bio-based products and energy.	(Authors' analysis)
IP20	Market Attractiveness	· Develop a portfolio of successful projects, initiatives, and business models to expand knowledge about the benefits of investing in infrastructure for collection, transportation, pretreatment, and storage of biomass resources.	(B.1.3)
		· Develop and disseminate a portfolio of guidelines and case studies about successful initiatives and business models for the introduction of bioproducts, bioenergy, and bioeconomy-related services in regional, national, and international markets.	(B.1.3)

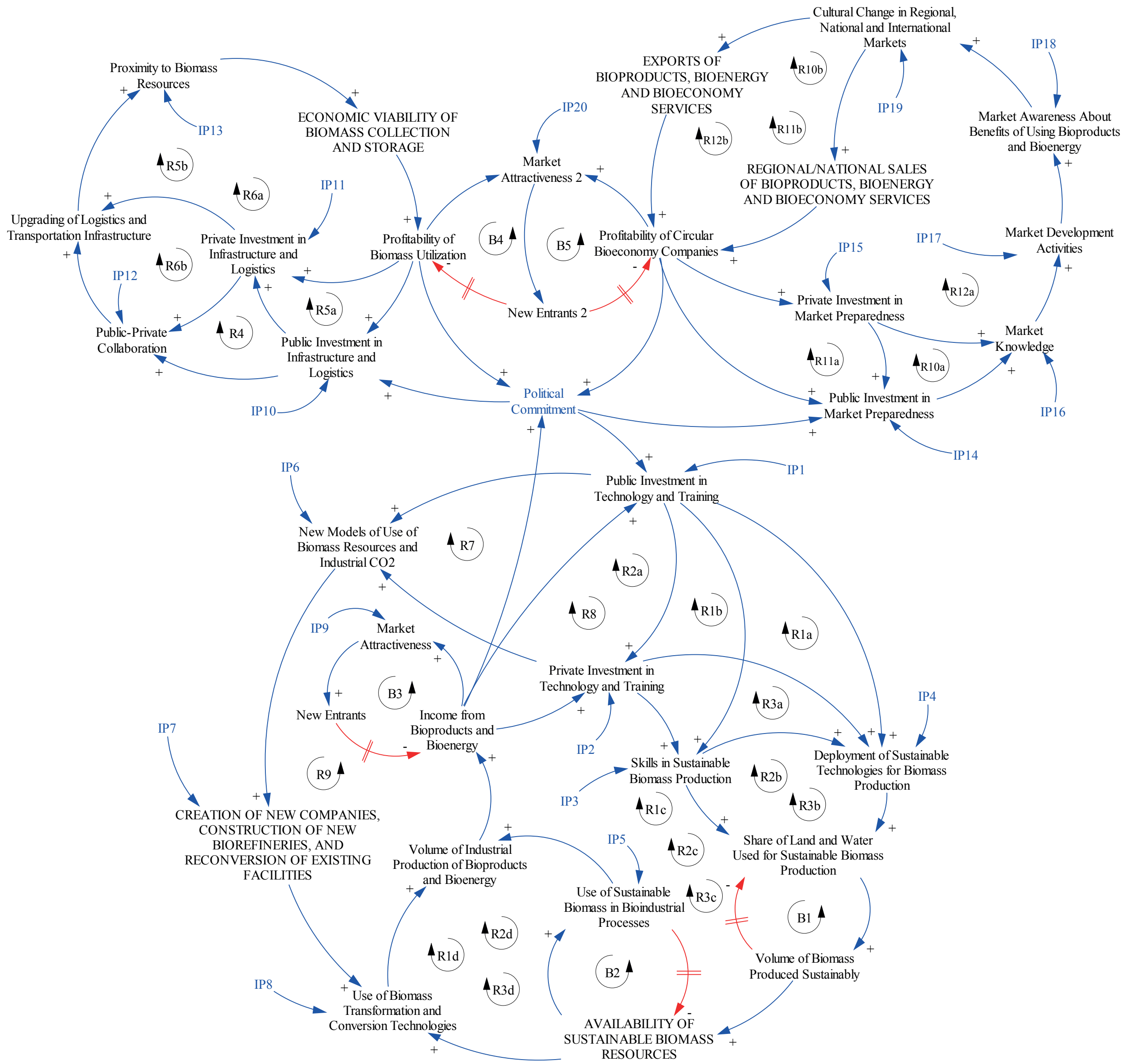

Figure 10. Integrated causal loop diagram displaying the main cause-effect relationships and causal cycles involved in the four strategic lines comprised in the Andalusian Circular Bioeconomy Strategy.

the imported technologies, whereas convergence failure occurs when the adoption costs are too high or when technology diffusion stops before it is completed. Furthermore, this model can successfully account for the fact that economies of transition regions are generally dualistic, i.e., small, traditional firms normally operate along with modern enterprises. In this scenario, it has been argued that when a technology is transferred from a developed region to less developed regions, the discrepancies between the labor skills lead to marked differences in factor productivity and output per capita and, for this reason, governments of less developed and transition regions need to increase their investments in human capital formation (Acemoglu and Zilibotti, 2001).

In this regard, our findings show that the role of government in supporting learning and knowledge-related processes is key for the development of the circular bioeconomy, which can be explained by the pervasiveness of information asymmetries in the sector, its intensity in knowledge and innovation, and its position in the confluence of several technological areas. This is supported by a recent causal mapping analysis of political structures in bioeconomic transitions based on the case of renewable energy political lobbying in six countries (Palmer et al., 2022), and is in agreement with the New Structural Economics framework postulated by Lin (2003, 2010), whereby the positive impact of government in this kind of scenario is higher when it seeks to help companies to overcome information and coordination costs about new industries, markets, and technologies; coordinate investment between companies and industries; and internalize the externalities linked to information by compensating pioneering companies through tools such as guarantees and fiscal incentives. Furthermore, from the innovation policy perspective, a combination of supply-driven policies aimed at the commercialization of research results will be required to foster the STI mode of learning, along with demand-driven policies aimed at supporting the DUI mode of learning for the development of products or services to specific markets (Isaksen and Nilsson, 2013). Lastly, due to the emerging nature of the concept, the circular bioeconomy sector is likely to require ongoing government support for some time, and for this reason political commitment to public investments in technology and training will be key to its success. In Andalusia, both the ACBS and the bill for the Circular Economy Law of Andalusia (LECA) that has recently been sent by the Government Council to the regional Parliament for deliberation are the two most important initiatives currently underway in this direction.

5. CONCLUSIONS AND FUTURE RESEARCH

The results outlined in this paper provide an initial understanding of the dynamics of Andalusia's bioeconomy and the identification of intervention points where targeted actions could be undertaken to accelerate the transition from a linear bio-based economy to a sustainable circular bioeconomy. The models generated in this study provide tools for a better understanding of the potential impact that interventions by governments and other actors could have on the development of the circular bioeconomy. Overall, when confronted with the current scenario, the preliminary cause-effect relationships and causal cycles herein described suggest that the Andalusian innovation system needs greater collaboration and coordination along and across the triple helix to support the development, commercialization, and diffusion of innovative solutions, all of which are necessary for the development of critical mass in this emerging sector of the economy. While the CLDs herein described provide structural insight into the system, an avenue for future research involves the development of quantitative models using stock and flow diagrams to evaluate the sensitivity of the intervention points, using historical data as a reference.

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