Horizon 2020 Societal challenge 5:

Climate action, environment, resource efficiency and raw materials

Deliverable 5.1

Report on EU sustainability goals: insights from Quantitative Story Telling and WEFE nexus

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Abbreviations

CAP	Common Agricultural Policy
COP	Cereals Oilseeds and Protein Crops
COPA-COGECA	Committee of Professional Agricultural Organisations – General Committee for Agricultural Cooperation in the EU
D	Deliverable
DG	Directorate-General of the European Commission
DG Agri	Directorate-General for Agriculture and Rural Development
DG Clima	Directorate-General for Climate Action
DG Comm	Directorate-General for Communication
DG DevCo	Directorate-General for International Cooperation and Development
DG Ener	Directorate-General for Energy
DG Fisma	Directorate-General for Financial Stability, Financial Services and Capital Markets Union
DG Just	Directorate-General for Justice and Consumers
DG RTD	Directorate-General for Research and Innovation
DG Sante	Directorate-General for Health and Food Safety
DG Trade	Directorate-General for Trade
EAAP	European Association of Agricultural Economists
EAP	Environment Action Programme of the European Union
EASME	European Commission's Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
EEA	European Environment Agency
EEB	European Environmental Bureau
EIP Agri	Agricultural European Innovation Partnership
EPSC	European Political Strategy Centre
EU	European Union
Eurostat	European Statistical Office
FADN	Farm Accountancy Data Network of the European Commission
FNI	Farm Net Income
FVD	Feasibility, Viability and Desirability
GHG	Greenhouse Gas
GLEAM	Global Livestock Environmental Assessment Model
GVA	Gross Value Added
H2020	European Union's Horizon 2020 Research and Innovation Programme
ha	Hectare
Hutton	James Hutton Institute
IUCN	International Union for Conservation of Nature
JRC	European Commission's Joint Research Centre
K	Potassium fertilisers
kW	Kilowatt
LCA	Life-Cycle Analysis
MAFF	European Union's Multiannual Financial Framework
MAGIC	Moving towards Adaptive Governance in Complexity
MDG	Millennium Development Goals
MEP	Member of the European Parliament
MS	Member State

MuSIASEM	Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism
N	Nitrogen fertilisers
NGO	Non-Governmental Organisation
NUTS	Nomenclature of Territorial Units for Statistics
NUTS2	Nomenclature of Territorial Units for Statistics, level 2 (basic regions for the application of regional policies)
NUTS3	Nomenclature of Territorial Units for Statistics, level 3 (small regions for specific diagnoses)
Natura 2000	EU's Natura 2000 Network
P	Phosphorous fertilisers
PNS	Post-Normal Science
QST	Quantitative Story Telling
SDG	Sustainable Development Goal (Agenda 2030)
SDI	Sustainable Development Indicator
Secretariat General	Secretariat-General of the European Commission
SMA	Social Metabolism Analysis
SWOT	Strengths, Weaknesses, Opportunities and Threats
TEEB	The Economics of Ecosytems and Biodiversity
t/ha	Tonnes per hectare
t/ha/year	Tonnes per hectare per year
UAA	Utilised Agricultural Area
UAB	Universitat Autònoma de Barcelona
UN	United Nations
WEF	Water, Energy and Food
WEFE	Water, Energy, Food and Environment
WFD	Water Framework Directive
WP	MAGIC project Work Package

Country abbreviations used in the chord diagrams

BEL	Belgium
BGR	Bulgaria
CYP	Cyprus
CZE	Czech Republic
DAN	Denmark
DEU	Germany
ELL	Greece
ESP	Spain
EST	Estonia
FRA	France
HUN	Hungary
HVR	Croatia
IRE	Ireland
ITA	Italy
LTU	Lithuania
LUX	Luxembourg
MLT	Malta

NED	Netherlands
OST	Austria
POL	Poland
POR	Portugal
ROU	Romania
SUO	Finland
SVE	Sweden
SVK	Slovakia
SVN	Slovenia
UKI	United Kingdom

Farm type abbreviations used in the chord figures

m.Crp	Mixed crops
m.C&L	Mixed crops and livestock
m.Lst	Mixed livestock
Perm	Permanent crops combined
s.Cat	Specialist cattle
s.COP	Specialist cereals, oilseeds and protein
s.Gran	Specialist granivores
s.Hort	Specialist horticulture
s.Milk	Specialist milk
s.Olv	Specialist olives
s.Or&F	Specialist orchards - fruits
sof.C	Specialist other field crops
s.S&G	Specialist sheep and goats
s.Wn	Specialist wine

UN Sustainable Development Goals

SDG1	No poverty
SDG2	Zero hunger
SDG3	Good health and well-being
SDG4	Quality education
SDG5	Gender equality
SDG6	Clean water and sanitation
SDG7	Affordable and clean energy
SDG8	Decent work and economic growth
SDG9	Industry, innovation, and infrastructure
SDG10	Reduced inequalities
SDG11	Sustainable cities and communities
SDG12	Responsible consumption and production
SDG13	Climate action
SDG14	Life below water
SDG15	Life on land
SDG16	Peace, justice, and strong institutions

SDG17	Partnerships for the goals

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Summary for Policymakers

This MAGIC report offers a pan-EU socio-ecological assessment of the EU agricultural and agri-food system, appraising the implications for progress towards Europe's own policy goals and the UN Agenda 2030, especially Sustainable Development Goal (SDG) 2, to End Hunger.

The analysis (Section 3) demonstrates that many aspects of European agricultural systems are not yet sustainable when considered over the long-term and against planetary boundaries. This is especially clear in terms of pressures on the environment and consequences e.g. for soil conservation and water quality (Section 3.4.2), but it also seems likely to be unsustainable in socio-economic terms, e.g. unviable businesses (Section 3.4.3). The findings especially highlight significant consequences arising from European agriculture's connections with the wider world (Section 3.4.4). Imported farming inputs, such as livestock feed, have a footprint associated with land use change, including deforestation, high rates of water use and harm to agro-ecosystem biodiversity in trade partner countries.

The Common Agricultural Policy (CAP) is a fundamental influence on European agriculture. Over time it has evolved, having more concern for the multiple dimensions of sustainability and the coupled climate and biodiversity crises. The CAP can, and should, be regarded as a 'nexus' policy since it has its own social, economic and environmental goals and is also expected to underpin progress in other policy domains (Section 1.1.4). However, this report's analysis highlights that CAP subsidies continue to be associated with farming systems that have higher environmental footprints, especially more intensive forms of livestock farming and specialist arable farming.

This analysis also highlights the scale of the challenge confronting the EU and the world. Current states do not match the desired outcomes from CAP nor climate, energy or environmental policies such as the Water Framework Directive and the Biodiversity Strategy. SDG2, especially its target for sustainable agriculture, is unlikely to be delivered within or beyond the EU under current arrangements. Improving policy coherence is already recognised as essential to achieving Agenda 2030 (Section 1.1.2), but although this is formally espoused by European institutions and policy instruments, the analysis suggests that achieving greater coherence remains a significant challenge. For example, the CAP is formally charged to support the Water Framework Directive, but the analysis shows many important elements of EU agricultural systems are associated with unsustainable patterns of water consumption (Section 3.4.2.6). Assumptions of only moderate global scarcity of agricultural commodities are no longer safe, yet it is often not feasible for them to be replaced by increased production within the EU. This suggests the EU cannot achieve its sustainability goals solely by focusing on farms and agricultural methods. There is a need to understand and potentially intervene in all aspects of the agri-food system, from processing, to retailing, exports and consumption. The interconnected policy trade-offs and governance challenges this entails should be seen as a sustainability policy 'nexus' intersecting the nexus of interconnected biophysical domains.

In this policy nexus, new approaches to generating, appraising, communicating and using knowledge about complex social-ecological systems are needed, especially to highlight partial framings, unconsidered externalities and potential unintended consequences. This is not solely about scientists better synthesising and transferring information to those in policy institutions, but also reforming how scientists and policymakers (and other actors) interact, especially where radical systemic change may be required. The experiences in carrying out this work, for example, challenges in engaging stakeholders, especially those responsible for policy coherence and Agenda 2030, and the types of responses received, suggest there is interest within EU institutions in change towards more sustainable and systemic approaches, but limited opportunity for such reflective transdisciplinary processes (Section 3.5).

Knowledge gaps and research needs (Section 4.5) range from political and policy science work on policy change and coherence, and on governing in complexity to achieve just transitions, through to methods for analysing and presenting complex systems. There are also clear and feasible ways to improve EU data collection processes to better support biophysically grounded sustainability assessments of both of farm systems and the wider agri-food supply chain. The proposed Farm Sustainability Data Network (EU Farm to Fork Strategy) should include data collection in terms of physical quantities as well as financial values – especially for the crop protection products and energy use, disaggregated by the existing geographical and sectoral frameworks. However, enough is known already to instigate change, without waiting for new data or methods.

Many policy actors have so far taken a cautious approach to change that relies on adjusting and updating existing policies. Whilst understandable in the face of austerity, political pressures and institutional inertia, the resulting incremental change is insufficient for safeguarding sustainability and achieving the policy goals formally adopted both by European-level institutions and their Member States. Failure to achieve sustainability objectives will eventually jeopardise the ecosystem services on which human societies depend, through climate change, biodiversity loss and environmental degradation. This report therefore reinforces the calls for radical changes in CAP and other policies, beyond those recently proposed, and also suggests that specific plans to achieve Agenda 2030 objectives are necessary, challenging assumptions that existing policy instruments will be sufficient by themselves (Section 4). To achieve this the whole agro-food system perspective of the Farm to Fork agenda needs to be complemented by specific instruments and, as noted above, new data.

This report's methodological approach is an innovative combination of quantitative analysis combined with policy research engagement, in a transdisciplinary process called 'Quantitative Story-Telling' (QST). QST combines and analyses existing European-level datasets in terms of their metabolic funds and flows, an approach called 'Societal Metabolism Accounting' (SMA). This accounting is informed by research into policy framings and processes, aiming to provide insights that are salient and thought-provoking for stakeholders. More information about this methodology is provided in Section 2. Whilst the results of this study are in line with messages from previous studies, the distinct contribution is the overview of European systems that also allows exploration of specific places or sectors, a coherent approach that can encompass both environmental and socio-economic issues, and the potential to appraise policy or other options for change, as well as diagnosing existing situations.

Given the urgent challenge of achieving sustainability within and beyond Europe, these insights will hopefully assist in motivating and achieving change.

Technical Summary

This MAGIC report offers a pan-EU socio-ecological assessment of the EU agricultural and agri-food system, appraising the implications for progress towards Europe's own policy goals and the UN Agenda 2030, especially Sustainable Development Goal (SDG) 2 to End Hunger.

The analysis presented in this report is the result of a methodological approach which innovatively combines a quantitative analysis with policy research and engagement, in a transdisciplinary process called 'Quantitative Story-Telling' (QST). The approach builds on the insights of Post-Normal Science (PNS), a field which brings attention to the process of science and knowledge (co)production. PNS emphasizes the need for articulation and rigorous examination of current problem framings and interests that dominate decision-making, as these have consequences in terms of perspectives and problems that are prioritised – and those which are not. In response, QST is conceived as a cyclical, iterative process. Its 'semantic' aspects (engagement with stakeholders and identification and articulation of dominant framings) are used to shape the 'formal' aspects of QST (the quantitative societal metabolism accounting). The overall QST process aims to provide insights that are salient and thought-provoking for stakeholders as well as scientists. More information about the methodology is provided in Section 2.

The findings from the QST cycle (Section 3) demonstrate that many aspects of European agricultural systems are not yet sustainable when considered over the long-term and against planetary boundaries. This is especially clear in terms of pressures on the environment and consequences e.g. for soil conservation and water quality (Section 3.4.2), but also seems likely to be unsustainable in socio-economic terms, e.g. unviable businesses (Section 3.4.3). The findings also highlight the significant consequences arising from European agriculture's connections with the wider world (Section 3.4.4). The 'footprint' of EU agricultural systems extends beyond the EU territorial boundaries in terms of both embodied land and labour. As a result, imported inputs such as livestock feed are associated with land use change including deforestation, high rates of water use and harm to agro-ecosystem biodiversity in trade partner countries. The Common Agricultural Policy (CAP) is a fundamental influence on European agriculture. Although CAP now encompasses multiple environmental goals, CAP subsidies continue to be associated with farming systems that have higher environmental footprints, especially more intensive forms of livestock and specialist arable farming.

The results of the analysis amplify messages from previous studies, highlighting the scale of the challenge confronting the EU and the world (Section 4). The current state of agro-ecosystems does not match the desired outcomes of CAP nor other climate, energy or environmental policies such as the Water Framework Directive and the Biodiversity Strategy. UN SDG2, especially its target for sustainable agriculture, is unlikely to be delivered within or beyond the EU under current arrangements. Ideas such as substituting imports with domestic production are unlikely to be feasible, so the EU cannot achieve its sustainability goals solely by focusing on farms and agricultural methods. The implications for sustainability and policymaking are interconnected with several important challenges for future knowledge collection and research.

The findings emphasise the importance of looking beyond economic value to material funds and flows, whilst recognising that overall food security is a result of how the EU food supply systems function in a globalised world. Improved data sets and analytic methods are needed to support this. To enable this, datasets must improve to allow exploration of metabolic patterns of socio-ecological systems, considering both the biosphere and the technosphere simultaneously. There are clear and feasible ways to improve EU data collection processes to better support biophysically-grounded sustainability assessments both of farm systems and the wider agri-food supply chain. Firstly, it is important to complement economic statistical data with biophysical statistical data, generated using a common accounting methodology. This enables a full, strong, sustainability assessment in a systemic manner which makes visible trade-offs and dependencies in time and space. The proposed Farm Sustainability Data Network (in the EU Farm to Fork Strategy) should collect data in terms of material quantities as well as monetary values. Such data is also needed beyond the farm-gate, to encompass other aspects of the agri-food system, e.g. processing, retailing, and household consumption. Lastly, all datasets are of most value when they can be disaggregated by a range of geographical and sectoral frameworks.

The QST methodology gave valuable insights on agri-food system sustainability, allowing multi-scale, multi-dimension, spatial and functional decomposition, bringing depth to the analysis of heterogenous EU agricultural systems. It enabled different datasets to be brought together in a coherent accounting structure, whilst the use of the chord diagrams and relationship maps identified different types of (un)sustainable patterns within a single frame of reference. SMA also draws attention to externalities and openness, which is also important in achieving the SDGs. The SMA mainly focused on agricultural production systems and there are possibilities to develop and refine its application to agri-food systems, especially if new data are available as noted above. Therefore, the promise of SMA was largely realised. However, it was clear that the most powerful presentations for stakeholders remained those of single dimensions and specific policy issues rather than an overview of the wider system. The report (particularly Section 3.5) highlights how the challenge of communicating complex issues and methods shaped the stakeholder engagement, and that the resulting impacts of using SMA or any complex methodology depends on the depth and quality of engagement.

The semantic aspects of QST (studying policy processes and engaging with policymakers) were shaped not only by the challenges of communicating complexity but also by the varying expectations, and roles of the policymakers. The analysis highlighted the complex governance system as a sustainability policy 'nexus' requiring attention, as well as how this governance system interconnects with the biophysical nexus. In particular, policy coherence is widely agreed as necessary to support Agenda 2030, yet the analysis shows its implementation is so far insufficient. Currently, there are limited instruments or approaches available to tackle this challenge.

The semantic work fostered salience and ability to engage stakeholders. The engagement within EU institutions (Section 3.5) , including challenges in recruiting those responsible for policy coherence and Agenda 2030, and varied responses received, suggest there is interest in change towards more sustainable and systemic approaches, yet limited opportunity for reflective transdisciplinary processes such as MAGIC within current institutional settings. It is possible that with more time and repeated interactions it might become possible to achieve this. For example, the cross-DG approach was appreciated for creating connections, but equally created challenges for open reflection and critique of the status quo, so in future, a sequence of group-individual-group interactions would assist. The insight that QST is a relational process is important methodological learning for future practical application. However, further work is required as the analysis uncovered paradoxes that cannot all be easily resolved. Aspirations to reframe and question the status quo can be in tension with advice about how to build relationships and share knowledge. These tensions and paradoxes arising in the data illustrate the importance of PNS scholars taking seriously the specificities of policymaking processes.

This report offers innovative insights about sustainability challenges facing European agro-systems, and methodological approaches for appraising complex systems whilst working with stakeholders. QST has the potential to highlight partial framings, unconsidered externalities, and potential unintended consequences. However, the well-documented challenges of interdisciplinary research on complex systems, let alone the challenges of transdisciplinarity and PNS, all require attention to achieve systemic change.

1 Introduction

One of the main objectives for the “Moving Towards Adaptive Governance in Complexity: Informing Nexus Security” (MAGIC) project was to bring the theoretically driven interests regarding governance in complexity into a real-world policy setting. The focus for WP5 was to consider issues of sustainability and how multiple European Union (EU) policy domains regarding water, energy and food interact in pursuit of explicit EU sustainability goals. The objective for this report was to illustrate the challenge of the current EU responses to the UN Agenda 2030, especially Sustainable Development Goal 2, target 2.4 (sustainable agriculture). As part of considering policy coherence required to respond to the UN Agenda 2030 and meet the SDGs, the report also responds to the original objective in the Grant Agreement for D5.1 “Report on the degree and nature of change that would be required for the policy narratives to be coherent with EU sustainability goals at the pan-European level considering the five policy themes”.

The report illustrates the evolution of the Common Agricultural Policy (CAP) to become more sustainable across the environmental and social as well as economic dimensions, and the attempt to achieve sustainability within conventional green growth paradigms. The EU commitment to the UN’s SDGs has drawn attention to the interaction between internal EU policy and EU external affairs, trade and development policy – and societal metabolism illustrates the often hidden dependence on material flows to or from beyond the EU. The report focuses on the gap between the scale of the challenge confronting the EU and the world, and the often cautious response by policy actors seeking to use incremental policy changes to bridge the gap between the current situation and the sustainability goals espoused by the formal institutions and their electorates.

This report does not focus on the environmental pressures associated with using agricultural land to grow biofuels, which is an important issue for agriculture and the water-energy-food and environment (WEFE) nexus. This omission is deliberate, given that the topic is well covered by other aspects of the H2020 MAGIC project, including the sister deliverable D5.2 (Jones 2020) that approaches the topic from the perspective of climate policy; and analyses of biofuels from an innovation perspective (Holmatov, Hoekstra, and Krol 2019); (Ripoll-Bosch 2020).

Central to the ‘MAGIC’ approach is the use of the Quantitative Story Telling (QST) cycle, including engaging policy actors, selecting themes of salience to EU policymaking, running societal metabolism accounting at the pan-EU scale and interpreting findings with policy actors. Thus, the report also captures “Lessons learned on policy QST: Integration of the lessons learned in the QST analysis of the different directives at the Pan-European level”. However, in keeping with the pan-EU and broad sweep of sustainability analysis, the focus here is on the underpinning assumptions or expectations within the framing of the policy issues (i.e. the narrative) not on the detail of the individual policies or measures per se.

This technical report contains the detail of the literature reviewed, the methodological choices made and many findings from all parts of the QST cycle, before a substantial discussion section. The rest of Section 1 contains background material. This section covers two major areas of background regarding the Topic (Section 1.1) and the Epistemology (Section 1.2). Section 2 covers the methodological choices made when implementing the QST cycle, to ensure that the approach could be repeated if desired. Section 3 presents the results of the QST cycle, including both the elicitation of views from EU policy actors and the quantified findings from applying societal metabolism accounting. Section 4 discusses the findings in light of the wider policy and scientific context, including ideas for further research and Section 5 provides the final conclusion.

1.1 Policy, scientific and epistemological background

This section covers two major areas of background regarding the Topic (Section 1.1) and the Methodology (Section 1.2). The topic background includes a description of the Water Energy Food and Environment Nexus (Section 1.1.1); the EU Sustainability Goals, now aligned with the UN Sustainable Development Goals (Section 1.1.2); the particular issues regarding SDG2: Zero Hunger (Section 1.1.3) and how the CAP can be viewed as a Nexus Policy. The methodology background covers the concept of Quantitative Story Telling (QST), through a discussion of post-normal science (Section 1.2.1); the principles of QST (Section 1.2.2) and the QST cycle (Section 1.2.3); and the concept of Societal Metabolism (Section 1.2.4).

1.1.1 The water-energy-food and environment nexus

The concept of the Water-Energy-Food (WEF) nexus has gained momentum since the 2011 Bonn Conference (Hoff 2011). The WEF nexus is a new perspective on longer term concerns about the impact of human activity on the planet and our ability to sustain current patterns, focusing particularly on the interactions of production and consumption within three domains of water supply, energy supply and food supply (Wiegleb and Bruns 2018). The nexus focus therefore combines both the provision of these resources from the biosphere and the conversion of natural resources into products and services through human activity in the technosphere. Whilst the WEF nexus approach takes a systems perspective in so far as it considers water, energy and food systems, it has been critiqued for treating these systems as pre-determined technical challenges to resolve, rather than as more general problem of how socio-technical systems are managed (Cairns and Krzywoszynska 2016). Building on this theme, Wiegleb and Bruns (2018) draw attention to the need to research the spatial distribution of impacts and the power, equity and justice dimensions that arise from such perspectives (Cairns and Krzywoszynska 2016).

Recently, some analysts have suggested adding environment or ecology to the WEF nexus, making it the WEFE nexus to ensure the link to impacts on the environment are explicit and not lost in the focus on the technical aspects of nexus management (Bidoglio et al. 2019). This emphasises the dependence of the water, energy and food systems on natural stocks and flows which also support aquatic and terrestrial ecosystems. The addition of a focus on the environment illustrates how security of supply for human use is dependent on ensuring planetary limits are not exceeded (Hoekstra and Wiedmann 2014; Rockström et al. 2009; Steffen et al. 2015). This focus on the biosphere is not only a technical issue but increases the range of stakes involved in these debates, as well as broadening the focus for assessing power, equity and justice. (Biggs et al. 2015) suggest that nexus is a useful tool for thinking about sustainability as the focus on 'security' that emerged from the 2011 Bonn conference links the nexus with livelihoods and the dynamics of decision-making associated with water, energy and food production.

1.1.2 European Union Sustainability Goals

When the research began, the European policy context was shaped by the EUROPE 2020 strategy that set out the objective for the Union to have smart, sustainable and inclusive growth (European Commission 2010). The EU had an overarching Sustainable Development Strategy (European Commission 2001), which was refreshed in 2010. This strategy built on the 7th Environment Action Programme (European Commission. 2013), which aimed to protect, conserve and enhance the Union's natural capital, have a resource-efficient and low-carbon economy and safeguard EU citizens from environmental risks and pressures. Part of the 7th EAP is the goal to achieve environmental integration and policy coherence, as illustrated by the drive for Member State Environmental Implementation Reviews, covering biodiversity, water, climate and bio-economic policy goals; and the goal to integrate natural capital objectives in other policies e.g. agriculture (especially the greening of the CAP), energy, cohesion and the requirement for the MAFF 2014-2020 to be directed to climate and environment goals.

The 7th EAP ends in December 2020 and the Council of Europe has called on the Commission to present proposals for an 8th EAP "Turning the Trends Together", recognising the role that EAPs play in guiding coordinated environmental and climate actions across the EU (Council of the European Union 2019). More recently, the European Green Deal was presented by the Commission to the Parliament in December 2019 (European Commission 2019d). The Green Deal is a growth strategy with the added goal of transforming the Union into a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases (GHGs) by 2050; economic growth is decoupled from resource use and no person and no place is left behind (European Commission 2019d: p2). The language here is reminiscent of the EU2020 Strategy and 7th EAP, suggesting an incremental development of policy goals, but there is a much stronger emphasis on social justice, signalled by the focus on both sustainable and inclusive growth. The Green Deal has an explicit international dimension, presented by the Commission as an 'integral part of this Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals' and also noting that the drivers of climate change and biodiversity loss are global in nature. The European Parliament has agreed some underpinning strategies e.g. Farm to Fork Strategy (European Commission 2020d); Strategy for a Circular Economy (European Commission. 2020). The Commission has recently published a communication on how the EU can respond to the current impacts of the COVID-19 epidemic (European Commission 2020a), which is likely to supersede or reframe the original Green Deal proposal. It suggests that the EU recovery should aim to accelerate the green transition, and strengthen the EU's 'competitiveness, resilience and position as a global player' whilst leaving no 'person, region or Member State behind' (European Commission 2020a: p1). The document illustrates the role of the EU institutions to even out the recovery process for the 'common good' (European Commission 2020a: p3), centred on a public investment programmes that must 'do no harm' to the environment and should prioritise green investments, particularly climate action (European Commission 2020a: p6).

Agenda 2030 and the proposed Green Deal are framed, and respond to, the global aspirations of the UN 2030 agenda (United Nations 2015) and the associated Sustainable Development Goals (SDGs) – indeed the Green Deal described as 'putting the Sustainable Development Goals at the heart of the EU's policymaking and action' (European Commission 2019a: p3). Agenda 2030 was adopted by world leaders in 2015 (United Nations 2015) to represent the new global sustainable development framework. This global commitment aims to eradicate poverty and achieve sustainable development by 2030, ensuring that no one is left behind. The SDGs balance the three dimensions of sustainable development: the economic, social and environmental. It specifies 17 SDGs, each of which has a number of specific targets. The Goals are explicitly acknowledged as interconnected.

The UN 2030 Agenda and its SDGs aim to 'improve people's lives and 'to protect the planet for future generations'. These Goals are designed to provide concrete objectives for all countries, focused inter alia on: human dignity, regional and global stability, a healthy planet, fair and resilient societies, and prosperous economies. In particular, SDGs 1 to 6 build on the core agenda of the predecessor Millennium Development Goals (MDGs), whilst Goals 7 to 17 incorporate new ideas (United Nations 2015). Three main principles that stemmed from the convergence of the MDGs and the Rio+20 Conference were used to shape the SDGs, namely : 1) leave no one behind; 2) ensure equity and dignity for all; 3) achieve prosperity within Earth's safe and restored operating space (UNEP 2019). Wysokinska (2017) (and others) note that shift from MDGs to SDGs to illustrate that Global North was part of the problem, increasing the likelihood of exceeding (or continuing to exceed) planetary limits.

Koff (2017) notes that the SDGs were supposed to be more transformative and global than the MDGs yet they have coincided with a swing to securitisation in many western countries; a similar point was also made by Lorenzo (2017). Pol and Schuftan (2016) note that the roadmap for SDGs (United Nations 2015) was non-binding and diplomacy softened or removed goals that threatened others. For example, food as a human right was overtly resisted by US and tacitly left out by EU. The EU Treaty of Lisbon adopts human rights, see Pol and Schuftan (2016: p3), but within the EU, although there is support for the human right to food within development policy, there is no such policy for within the EU. This analysis illustrates how there are contrasting interpretations of what each SDG means; differing ideals about how to achieve the goals (via free trade of commodities or supporting human right development) and intense political bargaining behind seemingly benign and positive aspirations.

Furthermore, there is an academic debate regarding whether the SDGs use a strong or weak sustainability framing, and whether the language of 'synergies' and relative silence on conflicts reflects a weak sustainability framing is more suited to policy coherence approaches found in the EU (Koff and Maganda 2016). The Policy Coherence for Development concept has been adopted in the EU (European Commission 2019c) but mainly to consider the impact of the Union on the rest of the world until now. There no longer seems to be a specific EU Sustainable Development Strategy but instead, the EU will support the overarching UN Agenda 2030 as set out the EC's reflection paper "Towards a sustainable Europe by 2030" (European Commission 2019a). As far as we can tell, there has not been a formal presentation of an EU strategy on implementing the SDGs beyond this reflection paper, possibly due to the changes in the Commission, Council and Parliament as a result of the 2019 elections and the associated impacts of Brexit, coupled with the impacts of the COVID-19 emergency. An excellent and more comprehensive description of the how the EU has come to adopt and embed the SDGs is available in "Europe's approach to implementing the Sustainable Development Goals: good practices and the way forward" (European Parliament 2019).

EU-level institutions may also take care not to try to supplant or replace national competences (the principle of subsidiarity). For example, individual countries make their own sustainable development plans and submit voluntary reviews as part of the UN governance, monitoring and evaluation of the SDGs (Stafford-Smith et al. 2017). (Rosati and Faria 2019) note how individual country institutional arrangements (rules of the game) affect how they understand sustainability and SDGs. Many of the policies delivering the SDGs are shared competencies between the EU and the individual Member States, which sets up a collective action problem and issues of policy (in)coherence between governance levels (Bodenstein, Faust, and Furness 2017). The implementation of the SDGs at the EU level is governed by a wide range of institutions, including the Council of the European Union, the European Parliament via various Committees, the Committee of Regions and the Commission, informed by views from a multi-stakeholder platform. Despite this, it is not always clear who is leading implementation, both within the Commission and throughout the EU institutions. Delivery of the SDGs is being monitored by Eurostat, using 100 sustainability indicators to cover all 169 Goals and targets. In May 2017, Eurostat published its own set of Sustainable Development Indicators (SDIs), comprised of 100 indicators, and in November 2017 Eurostat published its first annual monitoring analysis of the situation in the EU and its Member States, using this set of indicators (Eurostat 2017). Eurostat state they considered several factors when selecting the indicators. This included prioritising indicators that were already in use i.e. for reporting under existing policies. Most indicators are only used once for an individual SDG, but fifteen indicators are used multiple times, one is used three times and the others twice, for a total of 31 uses.

1.1.3 SDG2: Zero Hunger

The purpose of the SDGs is to ensure there is a more integrated and coherent approach to sustainable development than MDGs (Le Blanc 2015). However, Nilsson, Griggs, and Visbeck (2016) note that SDG interactions are essential for delivery but these are not discussed in the SDGs themselves (Stafford-

Smith et al. 2017). David (2015) shows how meeting many goals will require action and delivery of a target under another SDG heading, increasing demands for policy coherence, collective action and more holistic monitoring and evaluation; and in particular this is needed when looking at what David (2015) calls the CLEW nexus (climate, land, energy and water).

Policies on minimising trade-offs with SDG 12 (Responsible consumption and production) have been suggested to be the most effective at leveraging the whole SDG agenda and ensuring policy integration and coherence((Obersteiner et al. 2016). Norström et al. (2014) and Rickels et al. (2016) emphasise the importance of materiality and planetary limits and a need for stronger recognition of capital stocks (especially Natural Capital) as the framing underpinning SDGs. Vasseur et al. (2017) also believe SDG analysis needs to give more attention to how ecosystems underpin the goals – but in contrast to Le Blanc (2015) promoting SDG12, they believe that SDGs 6, 13, 14 and 15 are the foundational SDGs to focus on. Pradhan et al. (2017) draw attention to the need to consider conflicts and trade-offs within goals as well as between them to fully understand delivery of sustainability.

We have focused our analysis on a single SDG – SDG2 (Zero Hunger) to illustrate how even a single SDG is extremely complex, given intra-goal interactions between targets and indicators, as well as multi-level governance and policy implementation issues. The increase in ambition e.g. a goal to eradicate (not just reduce) hunger has been welcomed in the SDGs (Desta and McMahon 2015). This SDG covers five targets and three cross cutting actions – see Table 1 below[1]. Note action 2a. is specifically directed at the least developed countries. As set out in Section 1.1.4, target 2.4 is particularly pertinent to our five policy domains of interest, although agricultural productivity and incomes (target 2.3) is relevant to CAP, and genetic diversity is relevant to Natura 2000 and the Biodiversity Strategy.

Table 1: SDG 2 Goal, Targets and Actions

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.
2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.
2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.
2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries.

[1] https://sdgs.un.org/goals/goal2

2.b Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round.
2.c Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility.

When looking at the EU indicators for SDG2 (see section 1.1.2), the indicator choices suggest the EC and Eurostat perceive SDG2 is linked to SDG6 and SDG15, as it shares four indicators with these SDGs (see Table 2). Therefore, whilst the focus of this report is on SDG2, it is also on how aspects of SDG2 link across the five policy domains, to SDG6 and SDG15 explicitly, and several SDGs more implicitly (see section 3.4 and section 4 for further discussion).

SDG 6 (Clean Water and Sanitation) covers six targets and two actions. The most relevant targets in terms of thinking about WEFE policy integration are target 6.4 on water use-efficiency and target 6.6 that complements the overall objective of the EU WFD: "*By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*". SDG 15 (Life on Land) covers nine targets and three actions. The most relevant targets for a WEFE policy analysis are 15.1 "*By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements*", which links closely with Natura 2000, itself an instrument to enable the EU to meet international obligations; and also 15.3 (restore degraded land and soil) and 15.5 (reduce degradation of natural habitats, halt the loss of biodiversity).

Table 2: Mix of Eurostat SDI indicators used by EC to report on SDG2

6 Single use indicators	Obesity rate, Agricultural factor income per annual work unit (AWU), Government support to agricultural research and development, Area under organic farming, Gross nutrient balance on agricultural land, Ammonia emissions from agriculture.
1 Indicator shared with SDG6 Water	Nitrate in groundwater.
3 Indicators shared with SDG15 Terrestrial Biodiversity	Estimated soil erosion by water, common bird index, grassland butterfly index.

1.1.4 Common Agricultural Policy as a nexus policy

As shown above, the Common Agricultural Policy (CAP) is fundamental to the delivery of SDG2, although, as argued in this report, many other policy domains are also important. The objectives for the 2014-2020 CAP are:

- viable food production, with a focus on agricultural income, agricultural productivity and price stability;
- sustainable management of natural resources and climate action, with a focus on greenhouse gas emissions, biodiversity, soil and water;
- balanced territorial development, with a focus on rural employment, growth and poverty in rural areas (European Commission 2017b).

The availability of productive land, and decisions over how it is utilised, is becoming an important global consideration (see Goswami and Nishad 2018).The focus on the CAP is also salient due to its influence on large extents of land within the EU. In 2016, of the 447M ha of land in the EU28, 179M ha (39%) was within the area defined as utilised agricultural area (UAA), and of the UAA, 158M ha was potentially eligible for CAP direct payments, with 154M ha or 86% of the UAA determined (i.e. claimed and meeting all eligibility criteria). Taking an area-based approach illustrates CAP's relative importance when assessing interactions with the WEF nexus, due to the extent of interaction with environmental systems, even if agriculture is not an important policy domain when measured by economic indicators e.g. Gross Value Added to the Economy or proportion of employment within the EU. The CAP is also a large proportion of the annual EU budget, making the amount, geographic distribution and conditionality politically-charged decisions for the Parliament and its associated committees (see Figure 1).

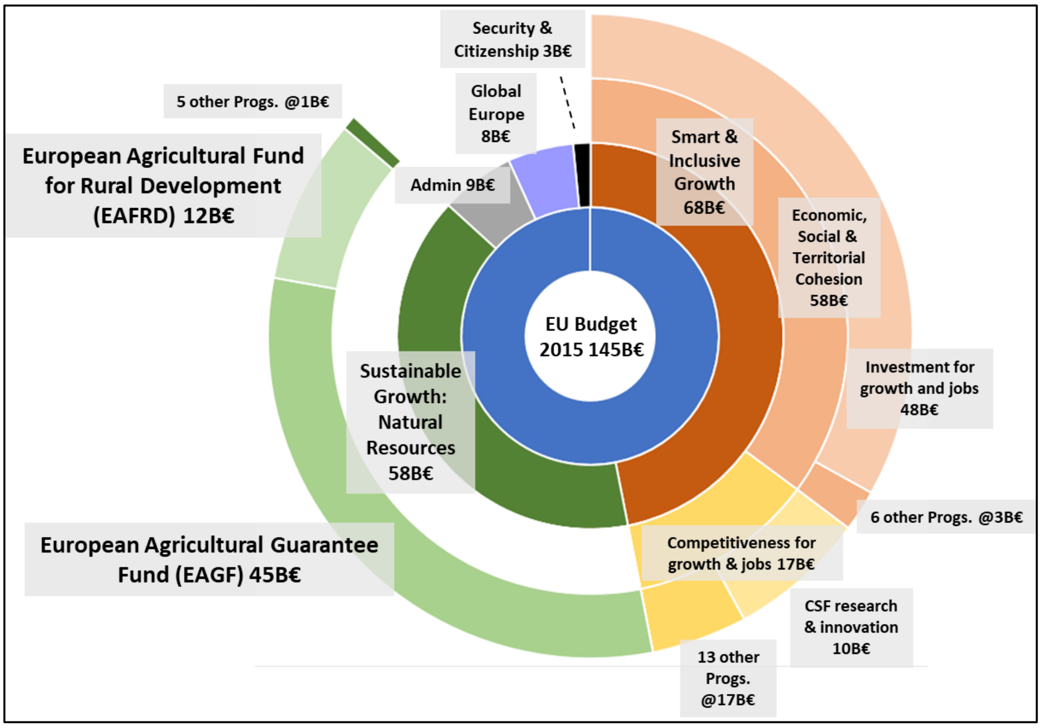

Figure 1: How EU budgets break down – highlighting the CAP (2015)

The availability of productive land, and decisions over how it is utilised, is becoming an important global consideration (see Goswami and Nishad 2018). This focus on agricultural policy is a proxy for Food in the WEFE nexus, given there is not (yet) a Food Policy governing the agri-food system for the EU. Whilst the CAP is not a substitute for food policy, it is the main policy domain by which food produced within the EU is regulated and incentivised. Beyond political importance and subsidies for land-based businesses, CAP is linked to the food security of the WEFE nexus, whereby EU agricultural policy is promoted on the basis of ensuring food supplies for EU citizens and on the basis of EU exports to the rest of the world (European Commission 2017b, 2018a). Furthermore, agricultural land covers an important proportion of the natural capital underpinning human wellbeing (Pretty et al. 2018); farmers are described custodians of these natural resources (European Commission 2017a) and agriculture is often imbued with cultural meaning and a source of individual, collective and national identity (Janker, Mann, and Rist 2019). These multiple perspectives on the objectives for agricultural policies can be seen in the revised objectives for the CAP post-2020, shown in Figure 2. This new framework is progressing through Parliament and the Committees with a revised implementation date of 1st January 2022.

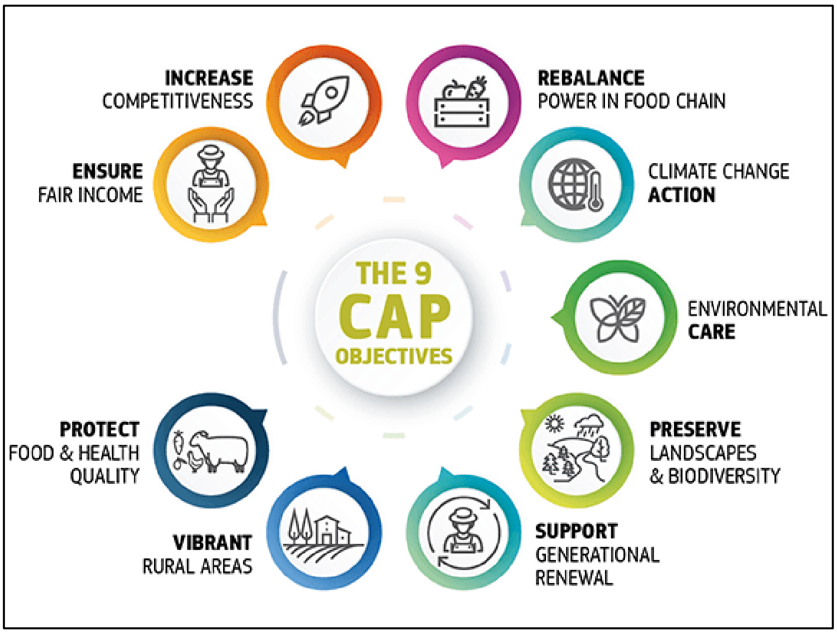

Figure 2: Nine Objectives of the Future CAP

This deliverable builds on the first phase of applying QST in MAGIC and therefore seeks to consider the interactions between CAP and policies related to water (mainly the Water Framework Directive and its daughter directives); energy (mainly the Energy Efficiency and Renewable Energy Directives); and the environment (mainly the Natura 2000 family of directives) as well as references to circular economy and the now-published Circular Economy Action Plan. Thus, a WEFE nexus analysis requires consideration of how CAP intersects with other policies pertaining to water, biodiversity, energy and circular economy (e.g. 'preserve landscapes and biodiversity' or 'climate change action' or 'environmental care' as well as socio-economic issues of income, competitiveness and generational renewal). The Water Framework Directive aims to ensure all EU waters (surface and groundwater) achieve good status (combining ecological protection, chemical standards and protecting flows/aquifers) with further objectives regarding coordination of measures, acting at River Basin scale, streamlining legislation, participation and pricing. The Natura 2000 policy aims to ensure the network of protected areas to conserve valuable and threatened habitats or species under Birds or Habitats Directive remains in favourable condition. Natura 2000 nests within the EU Biodiversity Strategy 2030 which aims not only to protect but also restore degraded ecosystems, and avoid further biodiversity loss, contributing to UN Aichi targets and the goal of no net loss of biodiversity. The CAP can contribute to measures to meet good ecological status for Water Framework Directive, through cross compliance (statutory management requirements, good agricultural and environmental conditions) and rural development measures. Natura 2000 is supported by Agri-environmental climate measures and farm advisory services, as well as Pillar I (basic payments, greening payments, payments for Areas facing natural or other specific constraints, voluntary coupled supports, small farmers scheme). These funding sources are described as 'key' to supporting implementation of these environmental policies (Alliance Environnement 2019b; Pe'er et al. 2017). Furthermore, the EU climate and energy framework requires at least 40% cuts in greenhouse gas emissions (from 1990 levels); at least 32% share for renewable energy; and at least 32.5% improvement in energy efficiency by 2030, which speak to the CAP objective for climate change action. Finally, the new Circular Economy Action Plan (European Commission. 2020) presents measures that include a focus on "*sectors that use most resources and where the potential for circularity is high such as: … food; water and nutrients*". The future CAP is described as having 'sustainability at its heart and provide new funding and incentives for climate- and environmentally friendly farming practices (European Commission 2020b).

The focus on security provided by a WEFE nexus perspective is a reminder that these resources are valuable and often under pressure. There is a wealth of academic and 'grey' literature on the environmental and social pressures generated by agriculture in the EU. The Commission's own Impact Assessment of the future CAP (European Commission 2018b) highlights the main environmental challenges facing EU Agriculture as: climate change, ammonia emissions from agriculture, unsustainable soil management practices, inputs of nutrients and pesticides, over-abstraction, and loss of landscapes and habitats. Economic challenges include pressures on farm incomes, weak competitiveness and imbalanced value chains and social challenges include under-employment and inequalities between territories and groups (European Commission 2018b). Certainly, academic commentary suggests that CAP's pillar 2 mechanisms may slow down (but has not reversed) the environmental pressures brought by intensive farming (Gamero et al. 2017). The European Environment Agency (EEA) has argued that the intensification of agriculture has enabled Europe to produce more and cheaper food but at the expense of the environment (European Environment Agency 2012, 2019). Such analyses have been recently supported by the findings of the (European Court of Auditors 2020) that concluded that CAP has not halted the decline of biodiversity on farmland.

The paradigm of sustainable intensification of agriculture – improving the environmental sustainability of practices to ensure the viability of the agricultural sector (Rockström et al. 2017) is often portrayed as having the potential to transform agricultural socio-ecological systems (Pretty et al. 2018). This is despite the concept being poorly defined (Mahon et al. 2017) and often perceived to be associated with high-input and high-tech farming practices (Godfray 2015), excluding wider social, cultural and welfare aspects of agricultural policy (Clay, Garnett, and Lorimer 2020).

Overall, (Norström et al. 2014) perspective on analysing sustainability remains pertinent for analysis of the SDGs, including SDG2 and its constituent EU policy interactions. They suggest three aspects to consider: 1) taking account of cross-scale relationships, feedbacks and uncertainty; 2) trade-offs between ambition and feasibility given biophysical, social and political constraints and 3) implementation of goals needs to consider what we know about social transformation processes at all levels, individual to global. Section 1.2 elaborates further how MAGIC tackles all three of these recommendations. This deliverable focuses on the transformative potential of EU institutions, particularly their formal institutional dimensions. MAGIC's contribution is to challenge the illusion of regulatory control via detailed policy measures by drawing attention to pressures that are hidden by analyses at single scale or single dimensions. As (Kuhmonen 2018) notes, the CAP is a tightly-wired and evolving complex adaptive system. MAGIC illustrates the fundamental preliminary step of considering problem-framing from multiple actors and multiple perspectives before any technical or policy solutions can be sought (Scown, Winkler, and Nicholas 2019).

1.2 Quantitative Story Telling (QST)

This section explains the aspects of the central methodology for this report – an approach called Quantitative Story Telling (QST). It first discusses the underpinning epistemology of Post-Normal Science (PNS), the overall concept of QST, the main stages in implementing the QST, and finally, more information about the quantitative approach – Societal Metabolism Accounting (SMA).

1.2.1 A post-normal approach to science for sustainability governance

Complex systems are composed of many interacting parts. The natural resource domains of water-energy-food and biodiversity, and their complementary policy and governance nexus, are the epitome of a complex system. This poses challenges for analysis, representation, and decision-making.

The emergent properties and behaviour of whole complex systems are not easily predictable from the behaviour of their individual components. As an example, a single catchment or watershed can be considered a complex biophysical system whose water flows cannot be perfectly represented and predicted: this complexity and unpredictability becomes even more true when considering the ecological, socio-economic components of that catchment. Systems theorists thus highlight the need to focus on emergent properties of the whole system and accept that their complexity is unavoidable (Anderson 1972). This also means that there can never be a single perfect representation of complex system, but instead multiple, non-equivalent and non-reducible representations simultaneously co-exist (Giampietro, Allen, and Mayumi 2006). The relevance and usefulness of these non-equivalent representations depends on the purpose of analysis (Giampietro, Allen et al. 2006). The emergent properties and behaviour of whole complex systems are not easily predictable from the behaviour of their individual components. As an example, a single catchment or watershed can be considered a complex biophysical system whose water flows cannot be perfectly represented and predicted: this complexity and unpredictability becomes even more true when considering the ecological, socio-economic components of that catchment.

The complexity of interacting biophysical and governance systems also highlights a need to recognise and work with multiple perspectives and knowledge claims. Multiple actors and institutions will be affected by and influence these systems, each with differing interests and perspectives on the system, priorities and problems at stake. This matters because natural, epistemic and institutional orderings are co-produced and tend to be self-reinforcing (Jasanoff 2004, 2005). They can be hard to identify and articulate, let alone reflect upon or change. Thus approaches which attempt to recommend single preferred solutions can be unhelpful, by 'glossing over' more profound ambiguities and potential conflicts (Stirling 2010).

In the 1990s, the approach of post-normal science (PNS) was proposed as a way to improve the use of science on issues where "*facts [are] uncertain, values in dispute, stakes high and decisions urgent*" (Funtowicz and Ravetz 1993). In contrast to modernist expectations of how science facts can be used, PNS brings attention to the process of science and knowledge (co)production, its (non)uses and consequences. PNS recognises multiple legitimate, but non-commensurate, perspectives and encourages the process of science production and use to be carried out with an 'extended peer community' rather than seeing non-scientists as passive recipients of scientific knowledge. When facing sustainability challenges such as climate change, it is important to "*recognise the ambiguities, voids and blind spots in our understanding of the world's complexity*" (Hulme 2010). Indeed many sustainability challenges are labelled 'wicked problems' because they encompass multiple forms of complexity, contestation and ambiguity (Game et al. 2014). Therefore, embracing the principles of PNS has been deemed vital for 'crisis' issues, with PNS even labelled a 'survival science' (Mehring et al. 2018). "*What is needed, is not only 'joined up thinking', but profoundly transformative change in infrastructures, organisations, behaviours, markets, governance practices and even cultures more widely. These are the challenges of 'the food, water and energy nexus' (or 'nexus')"* (Stirling 2015).

PNS emphasizes the need for articulation and rigorous examination of current framings and interests that dominate decision-making, and their consequences in terms of priorities, perspectives and problems that are articulated and prioritized (and, importantly, the priorities, perspectives and problems that are not articulated). However, at present, many analytic approaches do not reflect the insights of PNS. For example, discussions about risk and uncertainty to inform policy are normally framed quite narrowly, eliding the existence of many forms of uncertainty (Stirling 2010). As a result, the methods and tools used to appraise knowledge and support decision-making tend not to support a full appraisal the quality of evidence, its use or decision-making for sustainability.

The need for new approaches and new collaborations to improve decision-making on sustainability challenges has been acknowledged (Harris, Brown, and Russell 2012) including for agri-food systems

(Kuhmonen 2018; Waddock 2012) but finding these new methods or processes is not an easy task. PNS as conceived in the 1990s focused on insights or principles rather than proposing specific structured methods. Stirling (2010) advises that many "*practical quantitative and qualitative methods already exist but political pressure and expert practice often prevent them being used to their full potential*". Thus, existing practices exist that *can* be incorporated, but only in new transdisciplinary processes that use them to build engagement and encourage analysis that encourage reflection on current framings and their consequences.

The concept of QST is a response. It combines existing analytic approaches e.g. from the policy sciences, with innovative quantifications. Any analytic processes that focus on specific single issues, or claim to predict change, are likely reflect only certain value and knowledge sets, without even acknowledging a broader range of uncertainties and complexities. By contrast, QST aims to encourage reflection on the frames or worldviews that are embedded and reflected by existing thinking.

1.2.2 The principles and concept of Quantitative Story Telling

The concept of QST draws philosophically on post-normal science for governance (Mayumi and Giampietro 2006). It responds to the unavoidable scientific uncertainty and value plurality in decision-making within the nexus of water, energy and food policies. Tools already exist that allow modelling of parts of systems. However, the creation of new and better analytical tools by itself is insufficient to improve the quality of production and use of science in decision-making. There is a need for methods that not only summarise what and how we know the world, but also the need to consider how such knowledge is understood, prioritised, recognised and reproduced as problem framings or concerns by institutional arrangements. QST therefore aims to provide a process and set of tools that use quantifications of vital issues and underlying narratives or framings, as a means to stimulate informed reflection on the status quo, and to promote progressive thinking about nexus and sustainability issues.

The QST process sets out to make 'quality tests' of the narratives that underlie or justify key policy positions. The qualities of these narratives assessed are their feasibility (within biophysical limits – the biosphere), viability (within the existing technological and institutional context - the technosphere) and desirability (reflecting distributional and acceptability issues). The assessment is informed by quantifications on salient issues, using reformulations of existing statistical datasets and simple empirical transformations, using the rationale of societal metabolism (Renner, Giampietro, and Louie 2020; Giampietro and Renner 2020). That is, QST focuses on the funds of land and human time needed to create the flows of materials, energy and money that reproduce and maintain the identity of the system of interest (e.g. current patterns and trajectories of consumption). The analysis is conducted simultaneously across scales (geographical or classificatory) to highlight key externalisation effects and dependencies that may undermine long-term security. More information about these concepts is given in Sections 1.2.3 and 1.2.4.

It is intended that the 'semantic' aspects of QST – the engagement with stakeholders, identification and articulation of dominant framings - have equal weight with the 'formal' aspects of QST, the quantitative analysis or modelling of systems sustainability. This is because the quality of formal-analytic outcomes depend on clarifying the choices that have shaped the content of the 'evidence base' and the modes of analysis considered salient and credible (Saltelli and Giampietro 2017) . This creates the idea of transdisciplinary 'Mixed Teams', reflecting the goal that quantitative analysis should be not carried out detached from societal and policy context. Instead, QST aims to enrol and connect the ideas and framings of policy stakeholders with those of researchers with varied backgrounds in biophysical, social and data sciences, coordinated by staff with experience of working across the science-policy interface. Thus, the balance and connection of both the semantic and formal aspects is key to QST outcomes.

The outcomes that QST sets out for itself reflect post-normal ideas about the role and relevance of science, and the scale of current sustainability challenges. QST is not especially concerned with refinement of the minutiae of evidence but instead questions whether existing science-policy consensuses are ignoring existential threats because they take too narrow a view of the challenges faced by the EU. Examples of potential outcomes of the QST process could be for those engaged in it to reflect on the problems of policy inertia, recognise the importance of articulating hidden conflicts, or to reflect on the processes shaping evidence use.

1.2.3 Key stages and concepts in the QST process

QST is envisioned as a cyclical iterative process (Figure 3). The semantic phases broadly correspond with the top of the cycle, and the formal phases with the bottom of the cycle. The top of the cycle represents both the start and potential end point for QST, but successive iterations of QST are possible and indeed desirable.

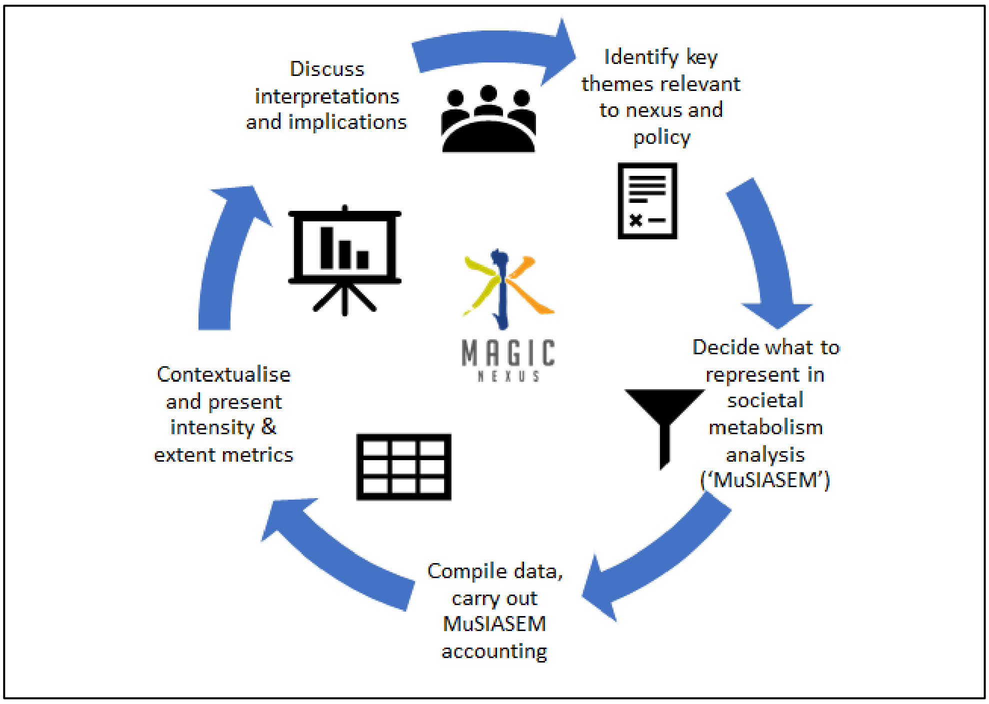

Figure 3: An overview of the Quantitative Story Telling (QST) Cycle

Each of the QST stages is introduced in Figure 3.

1. **Identify key themes relevant to nexus and policy** – this stage draws on desktop analysis and primary data from interviews and fieldnotes to identify the issues and ideas which are of interest to policymakers and other stakeholders. It also considers whether and how problems are represented in a semantic fashion and which actors are involved in presenting things as problems or otherwise. This approach shapes and initiates the formation of 'Mixed Teams' (comprising policy stakeholders as well as MAGIC scientists).

2. **Deciding what to represent in societal metabolism analysis** – this stage sees the development of a more specific shared understanding of what will be analysed. Section 1.2.4 explains the notion of societal metabolism and how it can be implemented in accounting frameworks, such as Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This stage moves progressively from deciding higher-level priorities (e.g. the type and numbers of narratives to be analysed) towards decisions on the specific aspects of systems that have to be represented (semantic

definitions) and other pre-analytical choices that will shape the later quantitative analysis (e.g. setting system boundaries, scales of analysis, functional and structural types, and useful indicators).

3. **Compile data and carry out MuSIASEM accounting** – this stage sees the formalisation (representation in the forms used in the process of analysis) of the systems relevant to the themes identified in stage 1 (e.g. a water body, an agri-food supply chain or an electricity-grid). In this stage the MuSIASEM Application is populated with quantitative data such that it becomes a complete formal representation of the system of interest and can be used explore the current state (diagnostic mode) and possible alternatives (simulation mode).

4. **Contextualise and present intensity and extent metrics** – in this stage, summary metrics are generated that assess the feasibility (within biophysical limits), viability (within socio-economic limits) and desirability (distributional, burden sharing and other outcomes like acceptable outcomes) of the system. The process of summarising and communicating the outputs tries to convey both quantitative and qualitative (semantic) uncertainties and sensitivities.

5. **Discuss interpretations and implications** – this stage sees the deliberation on and interpretation of the significance of the outputs of the QST analysis with stakeholders and the shaping of any further stages – either with new narratives or with alternative cases.

While this process is necessarily presented in this text as a linear process, albeit in a cycle that can be repeated, it is anticipated that there may well be occasions for some Mixed Teams, where insights gained within the QST process mean that it is desirable to return to earlier QST stages and to modify or refine the analysis. The intention is not to pursue ever-greater depth of partial analysis but to complete the QST cycle and generate meaningful outputs that stimulate deliberations with stakeholders.

1.2.4 Societal Metabolism Accounting and MuSIASEM

Societal metabolism accounting focuses on the funds needed to supply and consume the flows of materials, energy and money that reproduce and maintain the identity of the system of interest (e.g. current patterns and trajectories of consumption). These funds are typically land area, human time, and technology (expressed as power capacity). The methods also consider the draw by human-created systems (referred to here as the *technosphere*) on the natural capital within the biosphere where rates of usage may exceed rates of replacement.

Societal metabolism accounting considers both the extent and intensity of resource essential for identifying cases of Jevons Paradox, when despite increases in efficiency (assessed in intensive terms as a ratio between two flows, an input and an output), the overall take of resources increases (due to an increase in the size of the flows associated with an enlargement of scale of the process). In relation to this phenomenon, extent-based metrics are more significant where single resources or sinks are concerned such as the planet's atmosphere and intensity-based metrics are more significant when concentration, for example of pollutants, may locally exceed tolerable limits.

Societal metabolism accounting is better conducted simultaneously across scales (geographical or hierarchical/functional). Taking more than one non-equivalent perspective helps to better understand linkages between systems and the context of a system – region to nation, nation to EU, EU to global. It also helps illustrate the complex set of drivers, pressures and processes that confront policymaking in the WEF nexus. Given that the number and complexity of the entities being studied across these levels there is clearly a need for mechanisms by which these can be synthesised to provide meaningful insights e.g. for policymakers. In this regard the use of benchmarking is helpful and in social metabolism analysis, this is structured around three key concepts – Feasibility, Viability and Desirability.

Feasibility assesses the compatibility of an aspect of the technosphere (e.g. a production system, sector or society) with the biosphere in which it is embedded. Compatibility is quantified relative to external limits. These limits can be either hard or soft (where limits can be exceeded but only temporarily or with negative consequences).

Viability assesses the compatibility of one component of the technosphere with another (e.g. a production system with the demand from society or a regulatory regime). These are *internal limits* (within the technosphere) and are thus, at least to a degree, subject to decisions within and between governments and in wider society. Viability also is the intersection with externalisation, or the openness of the system, in other words, what external input flows and output flows are required to maintain the viability of the present technosphere.

Desirability refers to the compatibility of the operation of the system of interest with the normative values, goals and expectations of the people living in a respective society. As such, desirability can be assessed in terms of existing (or changed) distributional outcomes (e.g. of disposable income, life expectancy, education or other quality of life measures) or other measures of social acceptability. Desirability assessment requires the greatest degree of qualitative interpretation of MuSIASEM outputs and in policy terms this means the need for political processes of consultation and deliberation. Desirability is such a key consideration that it is present in and shapes all but the most mechanistic of the quantitative aspect of analysis. Recognition of this means that any analysis conducted to support policymaking needs to consider the process within which it is used. For the analysis within this report this is the process of Quantitative Story Telling (Section 2).

The quantitative engine used for conducting the social metabolism analysis of the wider MAGIC project is MuSIASEM (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism), an innovative accounting methodology having the goal of keeping coherence across scales and dimensions of quantitative assessments generated using different metrics (Giampietro et al. 2017). This has been applied in a variety of settings including Water, Energy, Food and Environment (WEFE) Nexus studies, see Giampietro et al. (2014).

2 Methodology

This section explains the materials and methods used to implement the Quantitative Story Telling procedure introduced in Section 1.2. Section 2.1 discusses how key themes were identified; Section 2.2 addresses how the iteration between the semantic and formal aspects of QST arrived at tractable stories to focus on in this QST cycle, whilst Section 2.3 covers how societal metabolism accounting was implemented. Given the importance of data in shaping what can be and was achieved, Section 2.3 explains how the analysis utilised existing EU data, whilst Section 2.4 explains the visualisation choices and how to read the diagrams representing the complex societal metabolism results. Finally, Section 2.5 discusses how the interpretation process was designed and implemented, including an addition of feedback interviews to help improve QST in the future.

2.1 Identify key themes relevant to nexus and policy

Stories relating to the SDGs were identified by building on past interactions (described in the report for Milestone 9 and Deliverable 5.5), conducting an institutional analysis on the SDGs in the EU, interviewing people who have worked on the SDGs in connection with European policy processes, reviewing the literature on the adoption of the SDGs by EU policy processes, and by participating in relevant conferences and seminars.

As part of step 1 in the QST cycle (*Identify key themes relevant to the nexus and policy*), researchers carried out an institutional analysis of the SDGs with the aim of understanding the way the SDGs are conceptualised and adopted by EU policy processes; identifying the appropriate actors with which to engage; and identifying stories to be analysed through QST. This analysis involved: first, a review of the main events relevant in the process of adopting and operationalising the SDGs by the main EU institutions. The review was carried out using search engines such as Google to find publicly available documents on the SDGs published by organisations at the EU level, such as the Commission, the Parliament, the Council, the European Economic and Social Committee, and the European Environmental Bureau. An examination of existing reviews of the progress towards the SDGs and EU-level analysis of delivery of the SDGs was undertaken to understand how the different goals intersect. An analysis was undertaken to find out what EU policies are expected to contribute to the SDGs. This analysis involved reviewing the EC's website[2] and EU official documents, such as the Impact Assessment of the proposed CAP post-2020. Finally, a review of academic literature on the role of the EU in the development of the SDGs was carried out using search engines such as Web of Science, using key terms e.g. 'Europe', 'Sustainable Development Goals' and 'Policy'.

In spring 2019, three semi-structured interviews were carried out with people who have worked on the SDGs in connection with European policy processes. The objective of these discussions was 1) to confirm what the project team had learnt from online or published sources about the connections between EU policies and SDGs; 2) to learn about further information that was not found using these sources; and 3) to seek other opinions and ideas on the role of the SDGs within the EU. Interviewees were identified through interactions with them in previous project events (through participation in seminars or interviews in the first cycle of MAGIC), through other events not organised by MAGIC, or through the participants themselves, who suggested colleagues who might be interested. For example, one interviewee from DG Agri invited a colleague to participate in the interview. Researchers also tried contacting officials from DG Env, DG RTD, Secretariat General and the Cabinet of the First

[2] https://ec.europa.eu/europeaid/ policies/sustainable-development-goals_en

EC Vice President, but officials either declined due to workload or did not reply. However, contacting them was useful for creating new contacts and raising awareness about MAGIC. Other people identified as potential interviewees, but who were not contacted, were officials from DG Sante, DG Comm, DG Trade. All interviews were audio-recorded and transcribed. These interviews were complemented with two informal conversations with members of the Secretariat General, who were unwilling to be formally interviewed.

Between May and October 2019, researchers participated in events to identify issues on the sustainable agriculture policy agenda. Kerry Waylen attended Green Week Conference in May 2019 hosted by DG Env, with speakers from other EC agencies and EU institutions, NGOs, think tanks and Member State policymakers. In May 2019, Keith Matthews was at the 172nd European Association of Agricultural Economists (EAAE) Seminar, attended by members of different DGs and other EC agencies. In October 2019, Kirsty Blackstock attended the Nexus Cluster workshop, a conference co-organised by the EASME and the EU Horizon 2020 projects Sim4Nexus, MAGIC and DAFNE, bringing together EU-funded projects related to the resource nexus as well as other non-EU-funded initiatives. Therefore, in addition to the interviews, researchers had informal conversations with relevant people from DG DevCo, DG Env, IUCN, EASME, and TEEB. It was expected that MEPs would participate in Green Week in May 2019 but they were absent, possibly because of the proximity of the Parliament elections. Through informal conversations and by taking careful fieldnotes at these events, researchers identified key issues on the policy agenda and individuals who might be interested in MAGIC events. The interview transcripts and notes on the events described above were analysed using NVivo 12 to thematically 'code' the content of these documents.

This deliverable also draws on the rich data held within meeting minutes and analytical memos. These captured ideas regarding how sustainable agriculture and the wider SDG agenda could be addressed using a QST approach, as well as challenges in implementing QST. For example, the language used has evolved from a focus on identifying narratives, to a more open language about themes on which to embroider stories. This evolution from narratives to themes is because the requirements of a full narrative analysis, which needs to be able to evidence a purpose for the narrative (that supports or undermines an action being taken related to a goal/moral); the main actors (heroes, villains, victims, allies etc) and a dynamic (beginning, middle and desired endpoint) were unable to be met. However, the idea of telling stories to make sense of complexity remains integral to this application of QST.

2.2 Decide what to represent in societal metabolism accounting

As part of deciding what to represent in the societal metabolic accounting (Step 2 in the QST cycle), researchers reviewed the EU policies and actions listed by the Commission as supporting the SDGs on their official website[3], and how these relate to the five policy areas studied in Phase 1 of the project. This review showed which SDGs are seen by the Commission as being most relevant to these policy areas. Researchers then identified SDGs that: 1) are being delivered in significant part by two or more of the subset of EU policies studied in Phase 1 of the project; and 2) are likely to have synergies or conflicts that can be quantified using MuSIASEM. This analysis found that there were over 180 links between these five policy areas and EU actions (policies, strategies or instruments) on these webpages, and these gave rise to around 250 linkages in total. The analysis also illustrated that all SDGs have some form of link to EU actions in at least three domains; and that our five policy areas each relate to many SDGs. However, we found that CAP had the connections to the greatest number

[3] https://ec.europa.eu/sustainable-development/about_en

of SDGs and has the most frequent connections for a particular SDG compared to the other four policy areas.

Further analysis was conducted on the metadata associated with the Eurostat SDIs, which also linked SDGs to specific EU policies. The Eurostat SDIs are a tangible representation of the SDGs. Each SDG was characterised regarding the indicators associated to them, and whether these indicators are used for multiple SDGs. Those Goals that had been previously identified as being most relevant to the Phase 1 policy areas were investigated according to the types of indicators associated to them. These combined results suggest a justification for focusing on SDG2 as it has, at least in terms of the indicators used, a water, food (land) and environment nexus focus, with only energy not explicitly referenced. The focus of SDG2, and its interactions with other SDGs and SDIs, is described in Section 1.1.3. Other SDGs e.g. SDG8 or SDG12 were potentially interesting but lacked a clear linkage to our focus on land, water and energy. A focus on SDG2 also allowed advances being made in MuSIASEM as part of WP4 to be operationalised and tested in a policy-specific domain that was not primarily energy or water-focused. During our interactions with policymakers, as described in Sections 2.1 and 2.5, it was clear that the now published 'Farm to Fork' Strategy was being developed and analysis that might inform this thinking was therefore timely.

During phase 1 (see D5.5), there was a suggestion that QST was used to explore issues surrounding increasing organic agriculture in the EU, which also became an emerging policy issue during this QST cycle. This was not pursued for two reasons. Firstly, the area of organic agriculture is a very small percentage of the overall extent of agricultural land in Europe, and a tiny fraction of the CAP expenditure. Given that QST aims to consider the degree and nature of policy change required at the EU level, this seemed to be diverting attention away from the overall agri-food system, to focus on a less significant aspect, both in terms of extent and intensity. Secondly, the combination of the accounting framework structure (MuSIASEM) and structure of the databases being used (see Section 2.3) made selecting organic agriculture as a separate farm type very difficult and would have greatly restricted the range of possible analyses.

SDG2 was conceptualised for our analysis as illustrated in Figure 4, and most focus was given to aspects of sustainable agriculture for reasons explained in Section 2.2. The SDGS, and the societal metabolism approach, emphasise a cross-scale approach, putting any activity within a global perspective. Our analysis was primarily focussed on how the SDG was being delivered within the EU, whilst recognising the dependence of flows from the rest of the world. A decision was made not to invest in trying to

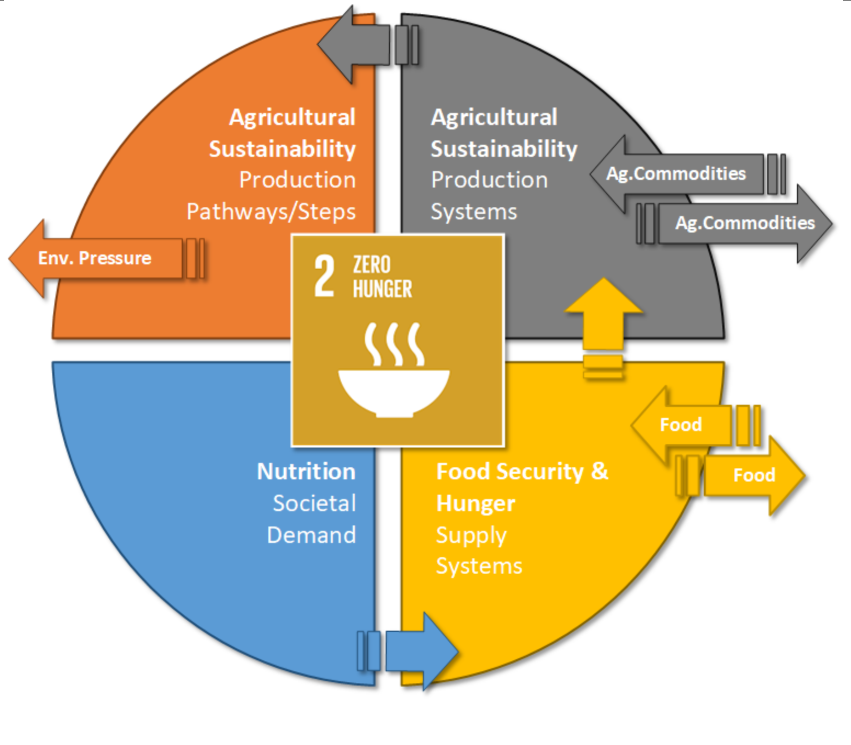

Figure 4: SDG for societal metabolism accounting

correlate different variables, as previously achieved in D5.5 (Matthews et al. (2018) but to focus on providing a wider range of different representations of the state of the EU agricultural system. Taken together these provide a portrait of where there are pressures, and in some cases proven impacts, on the biosphere and technosphere, that are sufficient to act as a 'quality check' and highlight whether and where a change in policy may be necessary.

From the analyses described above and building on the stakeholder interactions of Phase 1, the following story was identified: *"Sustainable agriculture is an important societal goal: it helps to support environmental policies as well as being a key component of SDG2. The primary policy associated with agriculture in Europe is the Common Agricultural Policy (CAP). The European Commission claim CAP enables sustainable agriculture, helps to deliver environment policies such as WFD and Natura 2000 and supports progress to the SDGs. However, others claim that EU agriculture is not sustainable. This harms European progress to achieve its sustainability goals both within and beyond Europe."*

Unlike the first stage (D5.5), the story was not formally or explicitly outlined to stakeholders nor were those likely to be involved in 'closing the loop' asked to nominate one particular story over another. This was because there was limited time between finalising the focus of the QST and planning the 'closing the loop' workshops, and to avoid stakeholder fatigue. A general email was sent in January 2019 explaining the focus on the SDGS, but not SDG2 in particular. The next communication was focused on the 'closing the loop' arrangements (September 2019).

2.3 Implement the societal metabolism accounting

The analysis here builds on that reported in MAGIC deliverable D5.5 (Matthews et al. 2018) and is not only contextualised by SDG2 but has undertaken a more comprehensive societal metabolism accounting using a specific instance of the tools and methods of MuSIASEM (Giampietro et al. 2017).

In terms of systems, four functionally distinctive levels have been considered with these four levels set in the context of **Societal Demand** (Figure 5). While specific societal metabolic analyses of the nature of demand and its implications in terms of nutrition, social practice and health are possible (Cadillo Benalcazar et al. 2014), in this case the resources available to the researchers mean that societal demand was treated as an exogenous driver. The four levels considered are:

Supply Systems that consider how demand within a society (and potentially elsewhere) is met through a mixture of local production and trade in food.

Production Systems that represent the mix of ways in which agricultural production is carried out – in this analysis, production systems are represented by fourteen farm types that are classified based on the value of their outputs. Production systems consider the aggregate outcomes of groups of farm businesses and this

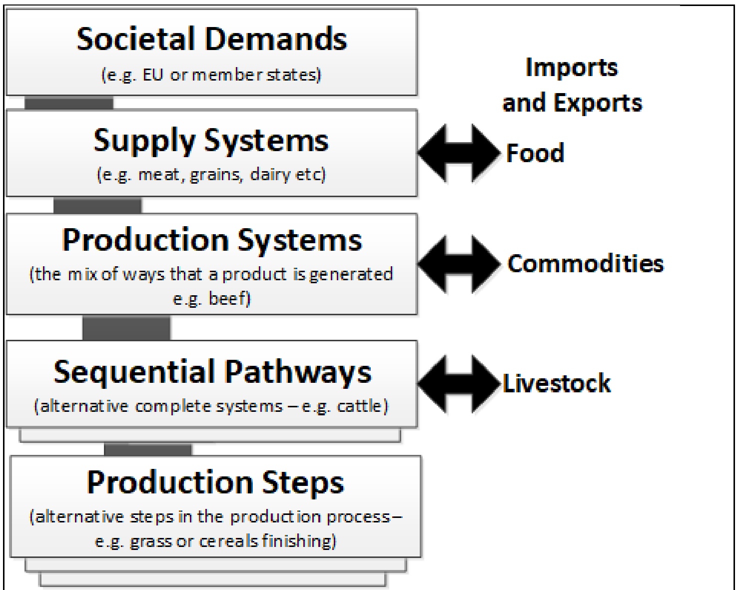

Figure 5: Agri-food systems

the level on which policy acts most directly through for example subsidy and regulation. Trade affects production systems through the import or export of agricultural commodities most notably livestock feeds.

Within Production Systems are **Sequential Pathways** and **Production Steps**. These levels are more specific representations of how individual enterprises within farm businesses are conducted. Here the diversity of management practices (with their varying consequences for productivity or environmental impacts) can be assessed. Within this deliverable the results are mainly concerned with outcomes at the Production Systems level, but the underlying data would allow study of particular livestock systems or individual crops as examples of sequential pathways and production steps.

Geographically the scope of the analysis is pan-EU since the desire was to be able to simultaneously characterize all of the land area to which EU policies apply and to elaborate the challenge inherent in having EU-wide policies that are relevant and effective in all circumstances. For granularity there was a desire to move beyond a reliance only on Member State-level statistics that can hide considerable regional diversity. Since the implementation of some EU policies can be developed to regional level, the representation of geographical diversity was highly desirable. Creating spatially explicit representation of societal metabolism via maps was also an ambition. Temporally the analysis covers the period 2014-2017, with data available per year but mostly presented as aggregates or averages for the period so that individual year events do not give a distorted view.

To implement societal metabolism accounting, tools and methods developed within WP4 (Giampietro et al. 2017) and in other projects by the UAB team (Renner et al. 2020 in press; Cadillo-Benalcazar, Renner, and Giampietro 2020) were brought together with data from the Farm Accountancy Data Network (FADN). This is a key dataset used in the development of EU agriculture and rural development policy with the benefit that the novel societal metabolic accounting is being based on a dataset that is familiar and credible (within known limitations) with policy stakeholders. FADN provides a detailed characterisation of a sample of individual farming businesses across the EU. Data on individual businesses or smaller samples can be made available with special permission, but for this analysis, data aggregated at FADN region (equivalent to NUTS2 or NUTS3) were considered sufficient.

The FADN data is a time series with publicly available data going back annually to 1990. This time series is through broken between 2013 and 2014 when revised protocols for data collection were implemented While many variables are preserved, and some data highly valuable to societal metabolic accounting were added, the break in the time series and the ending of some series is regrettable. For the deliverable, data between 2014 and 2017 (the most recently collated at the time) were used.

The FADN characterisation is most detailed in financial terms (reflecting the history of policy analysis questions and the methods used). The detail of how farm businesses are financially supported through the CAP are included and this is an essential element when considering how credible policy objectives and narratives can be. This financial detail, while not the primary concern of societal metabolic accounting, provides very valuable context that can combine both financial and physical perspectives. Where data are available only in financial form these can in some cases be translated into physical forms (e.g. value to tonnage) using price coefficients, either regionally or at Member State level. In other cases, the limitations of financial-only representation are limiting, and these cases are noted within the results as opportunities to consider revising the data included within FADN (most notably for crop protection products and energy use and machinery).

The biophysical data within FADN characterise the extent and intensity of land and livestock management systems. Data to the level of individual crops and animal types is available. The data within FADN details the flows of inputs used, the outputs created, and the funds of labour and capital used. Key data are the tonnages of agricultural commodities created and the land areas used. Particularly important for societal metabolic accounting is that within FADN for many crops it is possible to quantify the use of materials grown on the farm (autocatalytic use). This quantification is essential to understanding the degree to which livestock systems are making use of on-farm feeds rather than bought-in resources. For this analysis, the number of variables that could be made available was limited to 600[4]. The data was supplied for combinations of FADN region and farm type (used a production systems approach to categorisation) but where a class had less than fifteen farms present disclosure rules mean that no characterisation was provided.

MuSIASEM made use of the FADN data to generate the societal metabolism characterisations of both production and supply systems. This further developed the tools and methods from WP4 – the Marauder Map / MuSIASEM2.0. The MuSIASEM analysis involves the restructuring of the FADN data, the generation of technical coefficients[5] and the derivation of missing data values. The latter processes are described as the societal metabolic "sudoku" (Giampietro and Bukkens 2015). This complex process evaluates the consistency of data across scales and between uses – e.g. grass grown, and grass consumed by livestock. This identifies where there are missing or inconsistent data. For example, missing data for a farm type within a region can be derived from Member State-level statistics where sufficiently large numbers of a farm type may be present to generate a characterisation. Alternatively, "benchmark" values can be used from the most similar nearby region or derived from the literature. The ambition here is not to generate definitive data for every local instance, since it is recognised that there is an irreducible uncertainty in knowing how farm management is actually practiced. Rather the intent is to have a consistent and coherent societal metabolic dataset such that any macro issues identified within the analysis are robustly if not precisely characterised.

For the crop livestock interactions, the analysis relies on diet specifications from the GLEAM model (Haberl et al. 2018). The use of GLEAM allows detailed insights into the kinds of resources needed to generate flow of livestock products. While particular sequential pathways or production steps will differ from the GLEAM specifications, they do provide a quantification of livestock systems footprints that are not found within the FADN data. This is most significant where there are mixed livestock systems present, since it means the aggregate farm resource use can be better partitioned between production systems e.g. between meat and milk.

[4] By the access protocols for FADN.

[5] Either empirically derived from the data or benchmark values from the literature linking extents of flows (e.g. tonne of commodities) and intensities of fund required (e.g. area of land) to give intensities of use (e.g. yields).

The FADN-based societal metabolism dataset can then be used as a basis for exploratory, inductive or policy-led analyses through a process of selecting, presenting and contextualising the flows and funds making up the system of interest in terms of the extent and intensity of resource use (see Section 2.4).

The range of datasets, their purpose and source(s) are set out in Table 3.

Table 3: Datasets, purposes, and sources for the societal metabolism analysis

Dataset	Purposes	Source
Farm structure	Defining the funds of land, labour and capital. Farm typology.	FADN
Land and livestock use/management	Defining what land is used for and how it is managed.	
Outputs	The tonnages and value of agricultural commodifies created at the farm gate.	
Subsidies	Payments to farm businesses by type – links to expectations of outcomes.	
Price coefficients	Standard output coefficients for translation of economic output variables to biophysical output variables.	Eurostat
GLEAM	Livestock system feed coefficients – for estimation of use by livestock of agricultural commodities (on-farm use).	Haberl et al. (2018)
Forage production factors	Quantifying green water, labour, and other land-use technical coefficients.	Cadillo-Benalcazar, Renner, and Giampietro (2020)
Additional feed crop production factors	Quantifying - green water, blue water, human activity, fertiliser usage, and other land-use technical coefficients.	Cadillo-Benalcazar, Renner, and Giampietro (2020) Renner et al. (2020 in press)
Additional animal production factors	Quantifying blue water and labour technical coefficients.	Mekonnen and Hoekstra (2010) Cadillo-Benalcazar, Renner, and Giampietro (2020)
Herd composition	Quantifying the herd compositions per production system in each FADN region.	EUROSTAT – non avian species FAO – avian species
GVA	Relative importance of agriculture versus other sectors.	Eurostat - annual national accounts
Labour		Eurostat - labour force survey
Imports and Exports	Quantifying the externalised footprint, the geography of the footprint and where EU export are used.	DG Agri /Comext
Pollinator Index	Illustration of pressures on EU environmental funds.	Maes (2010) JRC
Soil erosion		Joint Research Centre (2015) JRC
Water quality		EEA - WFD
Water quantity		Schyns et al. (2019)

2.4 Present and contextualise metrics

This phase of the QST process focuses on how to create a salient, credible and legitimate presentation of the societal metabolism accounting. Data on such systems can, in common with the system they represent, be overwhelming in their complexity (Andersson and Tornberg 2018). This means there needs to be a process of presentation and contextualisation that and challenges existing tropes, narratives or conventions and is also accessible enough so that stakeholders continue to engage with the data yet does not over-simplify. From the ideas of Kahneman (2011) this means that the presentation of the societal metabolism accounting must be sufficiently engaging that stakeholders are prepared to make the cognitive effort to undertake deeper thinking and not resort to heuristic-based "*useful fictions*". Achieving such a delicate balance means there are both technical considerations - how data may be visualised as maps or charts of various kinds - and content considerations - which metrics are informative, which highlight issues, which highlight potential solutions. The former needs to seek to minimise the "*information to ink*" ratio, while not being so esoteric that the form becomes a barrier to the substance of the analysis. The latter needs to be strongly shaped by the learning in the earlier phases of QST – and particularly identifying where analysis can address concerns directly raised by stakeholders with whom the researchers are interacting. Kick-starting these presentational processes remains a key challenge since this inevitably means researchers making some choices before the first instances of presentation. Phases 1 and 2 of QST provide a robust basis for these decisions. Of course, having kick-started a presentational process, the ideal is to be able, over time, to repeatedly engage with the same stakeholders in a way that means there is social learning. On the researchers' side this shapes the content and presentation by better understanding the policy context, processes and phasing into which the analysis must fit, but on the stakeholders' side this means conceptual change and raising their ability to interact with new or unfamiliar data presentations.

2.4.1 Chord diagrams

The report makes extensive use of Chord diagrams (see example below). The particular form of chord diagram is that provided by the CIRCOS software (Krzywinski et al. 2009)[6]. These visualisations were developed initially for genomic datasets but have also been found to have potential value for aiding interpretation of other large or information rich datasets.

The chord diagram has a high information to ink ratio. It is able to demonstrate relationships between elements, across scales or between typologies, and so can be used to link countries and farm types, to show the mix of activities and resources used or created, or how funds are used. Chord diagrams are good for seeing the 'big picture' for example, highlighting the relative importance of extent variables, but are not necessarily best for showing fine detail. In most cases in this deliverable only the largest 25% of relationships are shown (top quartile) as these often encompass approximately 90% or more of the flows/funds. The chord diagram is also good for highlighting accumulated effects from multiple sources.

Since chord diagrams are not a commonly encountered visualisation it is worthwhile indicating how the visual language works to aid the reader in the interpreting the figures within the deliverable. Below is a simplified version of Figure 35. The figure shows the relationship between EU Member States and farm types in terms of the extent of the use of green water (rainfed in soil) and blue water (taken from surface and/or groundwaters) embodied in their imported animal feed.

[6] http://circos.ca/

In this report, all chord diagrams show countries on the right-hand side of the diagram (i.e. reading down from 12 o'clock) with the farm types on the left-hand side (from 6 o'clock upwards). A standard country-ordering has been maintained across all diagrams to ease interpretation, as per Figure 7. The order used combines size, proximity, and biophysical similarity but clearly other orderings are possible; this one was used for consistency and compatibility with the chord format. Countries are identified on the chord diagram by their three-letter identifier.

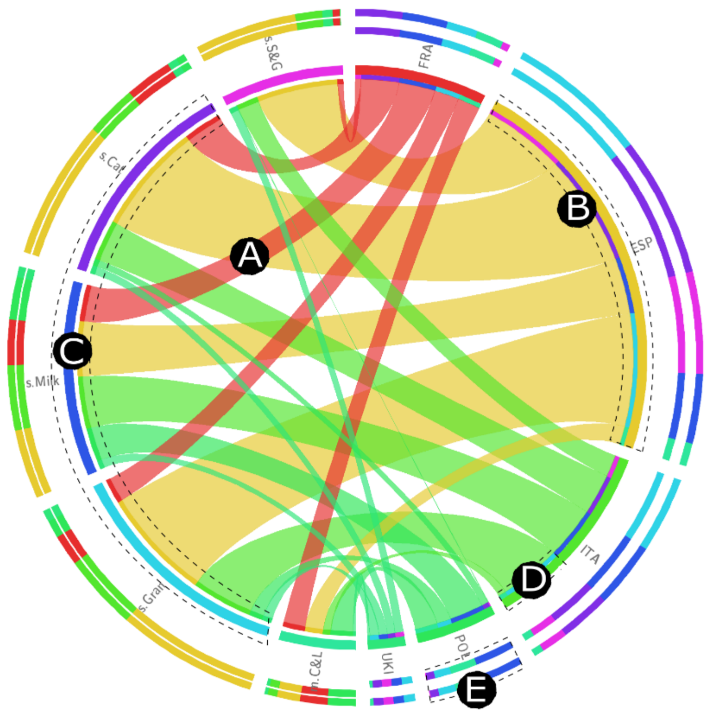

Figure 6: CIRCOS (chord) diagram example

Similarly, across all diagrams that show farm types, a fixed order is used, starting with more intensive and moving to less intensive, and from crop-based to livestock-based. Farm types use acronyms from Table 4.

Table 4: Farmtype acronyms used in the CIRCOS figures

1	Mixed crops	m.Crp	6	Specialist cereals, oilseeds and protein	s.COP	11	Specialist orchards - fruits	s.Or&F
2	Mixed crops and livestock	m.C&L	7	Specialist granivores	s.Gran	12	Specialist other field crops	sof.C
3	Mixed livestock	m.Lst	8	Specialist horticulture	s.Hort	13	Specialist sheep and goats	s.S&G
4	Permanent crops combined	Perm	9	Specialist milk	s.Milk	14	Specialist wine	s.Wn
5	Specialist cattle	s.Cat	10	Specialist olives	s.Olv			

The nature of relationships is encoded in the width and the colouring of the chords (A) linking the entities. The size of the segments around the perimeter of the core represent the extent of the variable encoded, showing relative importance: in this case Spain (B) is the country with the largest use of green water and blue water embodied in feed imports, whilst specialist granivores, milk and cattle are the largest farm types each with near equal size using this embodied water (C). The chords are coloured using each country's colours, so that it is possible – after having defined the relevant extent variable for the analysis - for each farm type to see the relative share for each country (the mix) and also, conversely, to interpret which farm types are the most significant for a particular country: for example, specialist granivores are significant for Italy (D). The outer segments e.g. for Poland (E) summarise the components present (farm types for countries and countries for farm types). These are ordered from largest to smallest, providing another visualisation of relative importance.

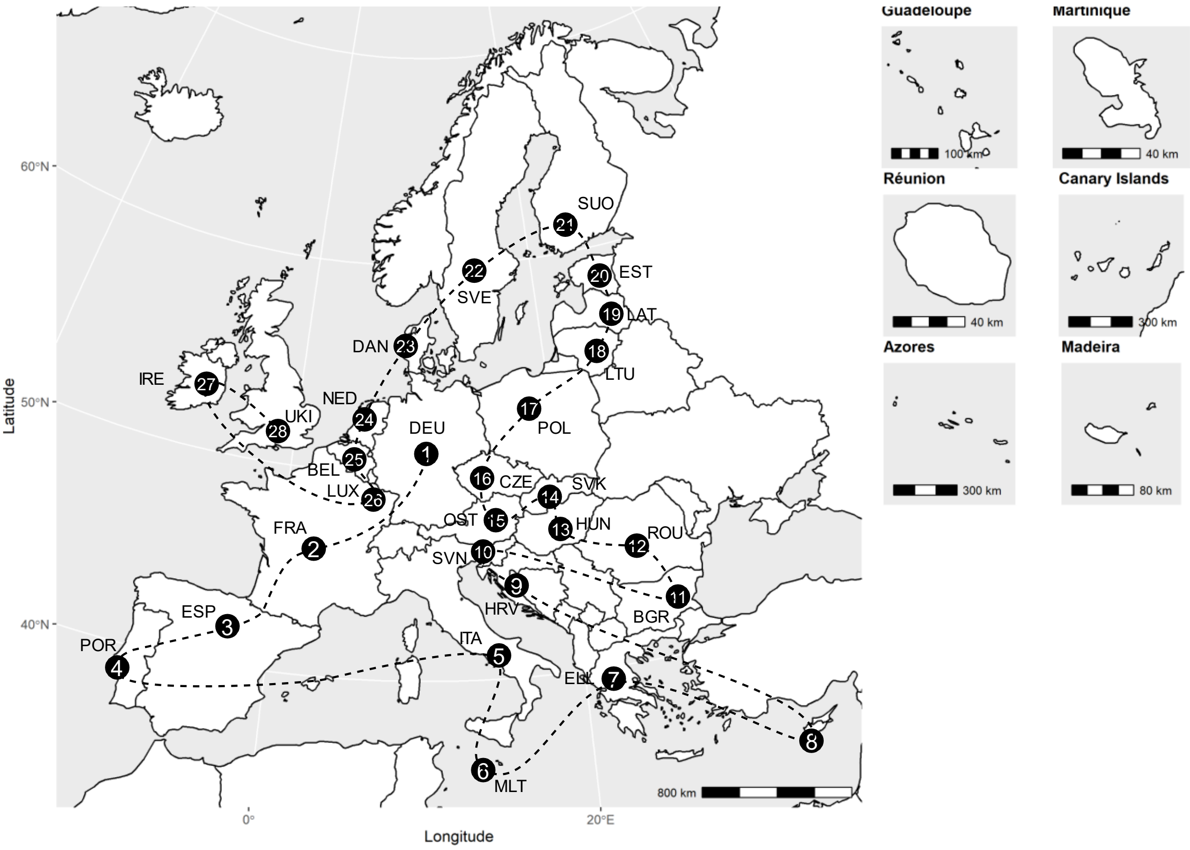

Figure 7: Ordering of countries in the CIRCOS diagrams

2.4.2 Relationship maps

The maps in this report are mostly of the form as shown in Figure 8. This shows the spatial pattern of a relationship between two variables. This can be in the form of two extent variables forming a relationship (a flow fund ratio), for example, tonnes of grain vs hectares of land used to produce grain. This implicitly creates a rate map (in this example t/ha), whilst maintaining the two variable values, defining that rate therefore allowing distinction of high/high locations and low/low locations, which on a standard rate choropleth would occur in the same class. An alternative form of these maps is an extent vs intensity map. In this case, the overall production of a given flow (the supply of the flow) can be related to a series of benchmarks (the productivity per unit of fund or the requirement of inputs per unit of fund). For example, the produced quantity of a given crop (extent) can be related to the yields of that specific crop or to the level of fertilisation, irrigation, pesticide application per hectare of that crop. In this way one can handle simultaneously qualitative aspects and quantitative aspects of the production process. For extent vs intensity maps, the extent variable is on the x axis of the legend (the size of the supplied flow), and the intensity variable (the benchmark determining the chosen flow/fund ratio) is shown on the y axis. These allow the display of both the share of the overall supply of the supplied flow from that region via the extent variable, as well as the pressure of use via intensity, e.g. tonnes of cereal, oilseeds and protein crops (COP) versus COP production per hectare in Figure 8.

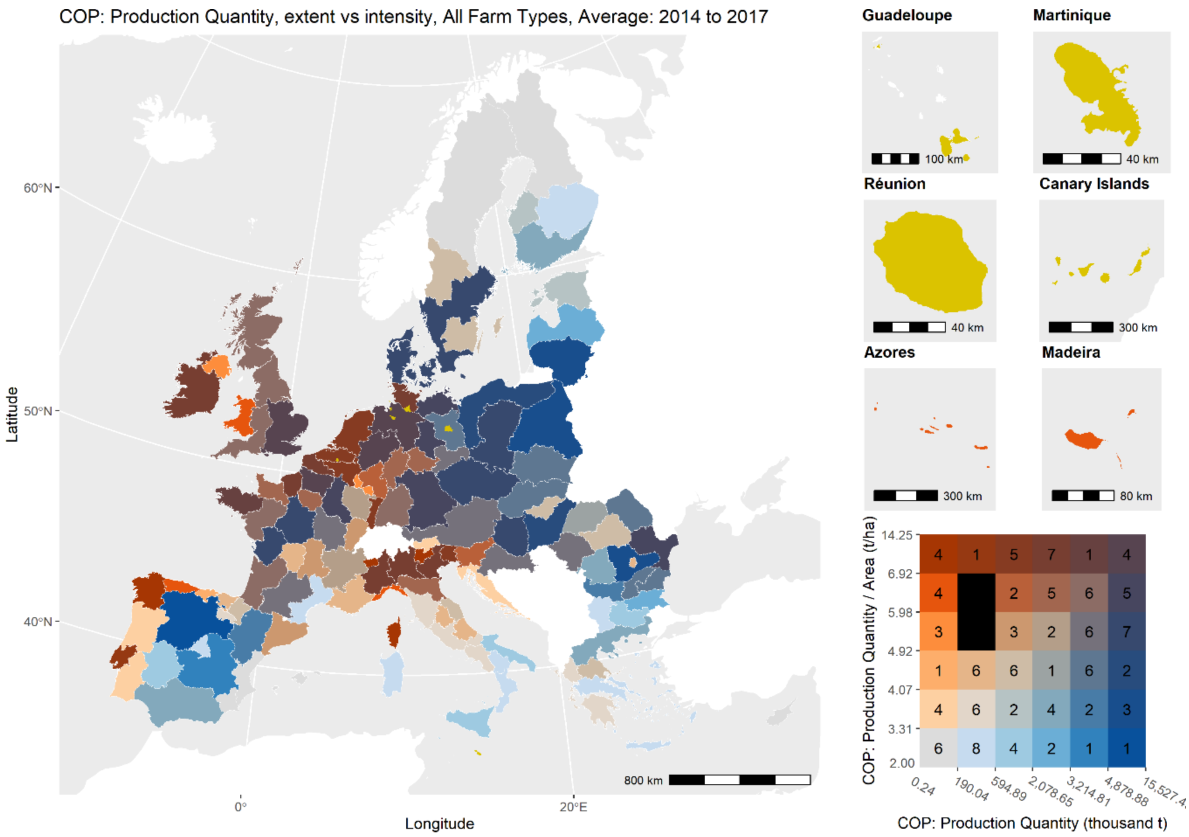

Figure 8: Relationship map example

The maps contain several important components. The main map display is of the mainland EU territory that is covered by the available data. The boxes on the right contain the outermost territories that the data available can cover, including the islands of Guadeloupe, Martinique and Saint Martin (shown in the same inset as Guadeloupe) in the French Caribbean, the island of Reunion in the Indian Ocean, the Spanish territory of the Canary Islands in the Atlantic Ocean, and the Portuguese territories of the Azores and Madeira in the Atlantic Ocean. The legend sits below these insets, and contains up to 36 different colours, each being a combination of the 2 variables being displayed on the map. The left and bottom edges show the class boundaries for the mapping, with the classes on each axis containing 1/6 of the values for that variable, so in Figure 8 as an example, 1/6 of all the regions shown have a COP yield rate of between 2.00 and 3.31 t/ha, and 1/6 have between 240 and 190,040 tonnes total output for the region. The number within the square indicates the number of regions that are within that class. A black box indicates no regions exist on that map with that combination of values. The yellow colour, shown below for the French and Spanish outermost regions and the city states in Germany indicates no data is available for these variables, usually because there is insufficient data in the FADN survey to report on that variable. It can also be a result of combining data from other incompatible datasets, for example combining NUTS regions with FADN regions.

2.5 Discuss interpretations with stakeholders

To complete the final step 5 in the QST cycle (*Discuss interpretations and implications*), several events took place between May 2019 and June 2020. This section explains how they were planned and carried out, similar to a description also available in the recent MAGIC report MS16 (Waylen et al. 2020). The methodology for phase 2 engagement should be seen as a composite, focused around the November 2019 event, but including and informed by prior engagement and leading to later engagement in 2020. This was a deliberate choice reflecting lessons learnt in phase 1: the team decided to try to contribute to or attend other events (such as Green Week) to help seize opportunities to build interest in the project, and to reduce the risks of relying on a single event. The interviews and informal conversations carried out also helped spread awareness of MAGIC.

The central event was a meeting with policymakers in Brussels in November 2019. The meeting had three objectives: 1) to explain the basic principles of MuSIASEM and raise awareness of it as a tool that could assist in more systemic analyses to support policy coherence and SDG delivery; 2) to communicate results of the analyses that suggest European agriculture is not fully sustainable and whose impacts outside of the EU must be considered; and 3) to promote discussion and feedback on these topics. The meeting was hosted by three researchers from the James Hutton Institute, drawing on work carried out with other colleagues at the James Hutton Institute and the Autonomous University of Barcelona.

Kerry Waylen first presented information about Societal Metabolism Accounting. The team described that this is a method illustrating metabolic patterns and interconnections of different systems. Central concepts are 'fund' and 'flows' of societal and environmental resources. In MAGIC, for any specific activity or system, the pattern of key flows and funds is represented in a 'processor' that can be connected with other processors in sequential pathways. The results of social metabolism accounting always characterise the state of the systems in terms of extent variables (e.g. land area in the case of funds, and overall supply in the case of flows) and also intensity variables (e.g. flow/fund ratios such as yields, rate of flows of water, fertilizers, pesticides per unit of land in production). Deciding what processes to represent, and how, depends on the question or problem to be analysed. Within MAGIC, societal metabolism is deployed within a broader process of reflection and stakeholder engagement called Quantitative Story Telling. As such, the seminar's focus on SDG2 arose from this process, and reflected prior engagement, interviews, discussion, and analysis of policy documents, to identify salient themes and challenges.

Keith Matthews presented data resulting from societal metabolism accounting of the pressures and impacts on the environment associated with agricultural production pathways. The presentation highlighted that some agricultural systems may be associated with adverse consequences for pollinator potential (use of crop protection products), soil erosion (arable cropping) and water quality (fertiliser use). The presentation also explored the consequences of interconnections and dependencies on countries outside of the EU, by considering the inputs associated with agricultural imports. These inputs reflect embodied energy, water, etc. use in systems outside of the EU. The consequences of re-internalising all these inputs were explored (e.g. growing all livestock feed within the EU), showing that large areas of land would be needed which may impact SDG 15 and other societal goals. There would also be social consequences, not least in terms of workload. Lastly, the presentation discussed how commodities, supply chains and nutrition could also be considered and connected as part of a societal metabolism approach. The researchers finished by presenting what they perceived as the general implications of this work, and asked the participants for their views on implications, and any other feedback.

The team had invited people who worked in the Commission who had some role or responsibility in relation to sustainability of agriculture. Many but not all invitees had previously had some contact with the MAGIC project. The team also invited people from various services of the European Commission, environmental NGOs with a Brussels presence, and a small number of MEPs.

The event was hosted at Scotland House, located on Schuman roundabout, because it is convenient for many working in the Commission/Brussels, but also because it is 'neutral' territory (it is not part of the official EU institutions). The cost of venue hire is also free for Scottish member organisations, including the James Hutton Institute. The event was styled as a seminar rather than a workshop, to emphasise that there was material to communicate in a comfortable format which allowed for discussion; the team decided to not place too much expectation on the participants having to 'work'. The seminar had the following format: lunch was available from 12:15. The event was advertised with a choice of three options, two of which were breakfast slots on other days, and lunchtime on the 21st was chosen as the date suiting the most. Giving people options may have helped them to realise that the team valued their participation. Registration was required which helped the team to plan the event. An Outlook calendar appointment was sent so that participants would receive reminders to travel and attend in time for the start of the main event. Ideally the main event would have been for 2 hours to enable more time for discussion, but it was limited to 1.5 hours to maximise attendance. On each table, participants were provided with a 'pack' of material: the slideshow, the agenda and seminar concept, a feedback form, a consent form, and a policy briefing on MuSIASEM. On a side table a selection of other MAGIC policy briefings was provided, some fliers about the James Hutton Institute were available. Name badges were provided for all participants.

Several follow up actions ensued from the November event. A 2-page memo of the event and the slides were sent to all participants; feedback forms were re-attached and requested at that time. This material is available on the MAGIC website and was also sent to people who had planned on attending but were unable to do so. The team responded by email to participants who raised specific queries or issues during the meeting. Feedback was received from five attendees.

The principal event that followed the November 2019 event was a European Parliament breakfast seminar hosted by Sheila Ritchie MEP in January 2020. Ms Ritchie had previously been invited to the November seminar was unable to attend. Invitations to this event were carried out by Ms Ritchie and her team, to whom we sent suggestions. The Hutton team used a format of three speakers from MAGIC (two from Hutton and the Principal Investigator from UAB), speaking for 10 minutes each in succession, with questions reserved for the discussion. The first speaker, Kerry Waylen, provided a rationale for why new perspectives and methods are needed to help all sectors of society think and govern more sustainably, and explained some basic concepts of Quantitative Story Telling, the team's policy analysis and the societal metabolism approach within that. Mario Giampietro provided examples illustrating why the external (extra-EU) impacts of EU agriculture urgently require attention, and emphasised the need think more about energy and other aspects of the agri-food system beyond production. Keith Matthews then reflected on implications for metrics and for research and policy that support sustainability. Each participant again received a pack containing the agenda, the slides, and 2-page briefings that provided more information about MuSIASEM and aspects of the work on agriculture. Other briefings derived from other parts of the MAGIC project were provided on a side table beside the entrance. The team did not try to prompt or structure the discussion that followed their presentation, but it was wide-ranging, including how to communicate complexity in the face of understandable desires for simplicity, questioning the role of the media and publics in shaping environmental debates, and discussion on why subsidies for biofuels had been introduced even though in hindsight, most now agreed they were unsuitable. Section 3.5 presents more detail on the responses and topics of discussion.

An online seminar with members of the European Environment Agency was held in June 2020. This took place at the request of officials from the EEA, some of whom had been invited but were unable to attend the seminar in November 2019. This seminar was originally planned for March 2020, but rescheduled due to the Covid-19 pandemic. The seminar was hosted by researchers from the James Hutton Institute: Kirsty Blackstock and Keith Matthews presented work building on the materials used at the November seminar, Kerry Waylen hosted and chaired, and Alice Hague and Alba Juarez-Bourke supported the running of the event. Following the event, attendees received the materials presented, a 2-page summary of the presentation and discussions, and a feedback form. A copy of the feedback form is attached in Appendix I. One attendee sent an email containing useful suggestions for refining the analysis and presentation of the approach. One participant requested a conversation, and a one-to-one follow-up meeting was arranged by videoconference.

Update emails were sent to participants who had expressed interest in November 2019, January and May 2020 informing them of the revised deadline for this report and links to new policy briefings, in light of Covid-19-related delays. We also shared information about our work on ‘Connect’, the intra-net of the Commission, via MAGIC partner JRC. We are unaware of any feedback or responses received via this platform. A further event was planned in Brussels during Green Week in June 2020, but this had to be cancelled due to Covid-19.

Between April and June 2020, feedback interviews were carried out with stakeholders who had previously interacted with the project. The interviews were led by a researcher with no previous involvement in the project, to enable interviewees to be candid in their assessments. The aim of these interviews was: 1) to help complete the Hutton’s CAP/SDG 2 QST cycle by prompting participant reflection about whether our stories and their quantification helped them think about issues and/or change the policy stories; and 2) to help understand how, and why, QST played out, especially if it did not run as expected (i.e. to prompt discussion and reframing on dominant policy stories) and how QST could be improved. Together these two points aided reflection on the MAGIC project more broadly. The researcher approached thirteen previous participants through existing contact information, and received ten replies. Six people indicated they were unable to participate in the feedback interviews (including because they had changed jobs, or were on parental leave). Interviews were undertaken via videoconference and were audio-recorded and transcribed. In total, four interviews were held with representatives of the Commission and agencies with an average interview length of thirty minutes.

Transcriptions of the interviews, notes taken during the engagement events, and feedback received from stakeholders were analysed using NVivo 12 to thematically ‘code’ the content of these transcripts according to the different aspects of the QST cycle referred to, and to the type of response or reaction of the interviewee. Full saturation was not achieved in our primary data. This is unsurprising, given the relatively small numbers engaged across the huge potential ‘population’ outlined in Section 3.1. However, the primary data from interviews and field notes provided a very useful complement to official documentation and the combined data provided a comprehensive resource from which to contextualise the quantitative elements of QST.

All subjects gave their informed consent for inclusion before they participated in the study. The study protocol was approved by the James Hutton Institute’s Research Ethics Committee. The data collected was processed, stored and managed in compliance with U.K. law and the EU General Data Protection Regulation. Participant identities are anonymised in this and other outputs, so where quotes or information from participants are used, they have been given pseudonymised initials.

3 Results of application of QST

3.1 Our 'Mixed Teams' – Who was engaged in QST, how, and why?

The stakeholder engagement aspect of the project focuses on the EU-scale, targeting mainly EU institutions, in accordance with time and resource availability. These interactions were closely linked to SMA cross-scale quantitative results, with SMA results being presented to stakeholders, and their views informing the interpretation of results. Researchers aimed to engage people connected with EU policy processes, and in particular those with expertise of MAGIC's policies of interest and their progress towards the SDGs. As the institution responsible for making policy proposals, the Commission and various of its agencies were the main institutions targeted. Other EU institutions that engaged in the process were the European Environment Agency and the European Parliament. Lastly, researchers targeted members of think tanks, NGOs and lobby groups.

Stakeholders engaged in two steps of the QST cycle: step 1 (*Identify key themes relevant to the nexus and policy*) and step 5 (*Discuss interpretations and implications*). The institution that researchers engaged with the most, in both steps of the QST cycle, was DG Agri, including Directorates A.1, B.2, C.2 and C.3. This was in part because the team had already built connections with this organisation in the previous cycle of MAGIC, as described in Deliverable 5.5. Other agencies researchers interacted with several times are DG DevCo, DG Clima, DG RTD, EASME and EEA. Some of the people in these organisations (DG DevCo, and an environmental think tank) were previously part of DG Agri so could still have a 'DG Agri perspective'. Some individuals from different organisations (DG Agri, DG Clima, DG DevCo, DG RTD, EASME, EEA) interacted with the project several times throughout this cycle of the first QST cycle (in 2017-2018), giving them a deeper understanding of the project. Researchers also attempted to engage with people from other relevant Commission agencies, but were either unable to, as in the case of DG Sante, or had limited success, in the case of DG Env. These findings are illustrated in Table 5:

Table 5: Stakeholders approached for QST

		Step 1 of the QST cycle (interviews)	**Step 5 of QST cycle** (seminar, Parliament breakfast, webinar)	**Debriefing Feedback interviews**
Commission agencies	Cabinet of the first EC Vice president			
	Commissioners for DG Clima, DG Agri, DG Env, DG ENER, DG DevCo			
	DG Agri			
	DG Clima			
	DG DevCo			
	DG Env			
	DG RTD			
	DG Sante			
	EASME			

	EIP Agri			
	European Political Strategy Centre			
	Eurostat			
	JRC			
	Research Executive Agency			
	Secretariat General			
Other EU institutions	EEA			
	EU Parliament			
Civil society, Think tanks, NGOs, Lobby groups	CEPS (Centre for European Policy Studies)			
	COPA-COGECA			
	Environmental think tank "A"			
	Environmental lobby group			
	Environmental NGO			
	Environmental think tank "B"			
	Think tank			
	Advocacy NGO			
	University			
	WWF-EU			

Green cells show who we interacted in each stage. Orange squares represent institutions we tried contacting unsuccessfully. Light green cells indicate that someone we interacted with was formerly in that organisation (Environmental NGO, environmental lobby group), is temporarily seconded there (think tank)), or participated in a lesser way (DG Env). Note that this table does not include organisations with which we did not try to engage. Some of the organisations' names have been changed to protect participants' anonymity.

Stakeholders from different organisations presented contrasting views regarding the progress made towards the SDGs, as well as about the role of the EU in their implementation. These differences may be related to the individuals' roles and the organisations they represent. For example, the interviewees from JRC and the advocacy NGO had a similar focus on the implementation of all SDGs across the Commission (although they had divergent views on the progress made towards the SDGs, and what measures are needed), while the interviewee from DG Agri focused on the intersection of the SDG agenda with the DG Agri work programme. Interviewees' different opinions may also have been shaped by their previous experiences and by personal interests in these types of methodologies. For example, two of the interviewees (from the JRC and the advocacy NGO) said they have an interest in systems thinking, possibly making them more willing and able to engage with approaches such as SMA and QST. However, the respondent from DG Agri said they tried not to let their personal views influence their answers: "*Well you know, we are civil servants, so our personal feelings are not important, we are loyal and so on*" (SD).

These views were complemented by the analysis carried out in the previous cycle of the project and by the institutional analysis and literature review described in Section 2.1. The conversations helped researchers identify relevant actors to engage with, as well as the stories and themes relevant to the

SDGs. Respondents emphasised the role of the following in the governance of the SDGs: the Secretariat-General, DG Agri, DG Clima, DG Env, DG Trade, DG DevCo, DG Sante, DG Fisma, DG Just, EPSC, Eurostat, the Council, the Parliament, Member States, and the UN. One interviewee from the JRC emphasised the importance of the project engaging with policymakers involved in externally-facing policies, such as development policies: "*development policies [are] very important and then also the negotiation with the Member States, negotiation with the United Nations and their negotiation as well. I think that somebody from the external action or development is good"* (KS). Speakers at Green Week highlighted the role of NGOs in lobbying for change, raising awareness and as watchdogs, confirmed in interviews with SD and JR. Interviewees also pointed out the importance of the private sector: "*the private sector has an interest and started engaging in various work and that matters for the leverage and the delivery*" (SD), alongside trade unions and the media as relevant civic society actors.

As part of step 5 in the QST cycle (*Discuss interpretations and implications*) stakeholders participated in several events: a seminar in Brussels in November 2019, a breakfast seminar with the Parliament in January 2020, an online seminar with the EEA in June 2020, and some final feedback interviews. The seminar in November 2019 was attended by 15 people: one person from an environmental NGO and the rest from various services of the Commission (DG AGRI, DG RTD, DG DevCo, DG CLIMA, and EASME). Some but not all attendees had prior knowledge of the MAGIC project. Five attendees (from DG Agri, DG DevCo, EASME) completed feedback forms or wrote feedback emails on the event. One additional person from DG Env, who had been unable to attend, also sent feedback on the summary and materials presented, which had been distributed to those unable to attend. Most attendees had participated in previous project events or were suggested by other invitees. For example, one participant from DG Agri forwarded the invitation to several colleagues, who also attended. Other attendees were identified as having authored relevant documents, or through the organisational charts of relevant EU agencies.

Researchers also invited people from other organisations (DG Env, DG Sante, JRC, European Environmental Bureau, European Environment Agency, European Parliament, Secretariat General, European Political Strategy Centre, Eurostat, the Research Executive Agency and an NGO) but they were either unwilling or unable to attend on the selected date and location. Some people replied to the invitation saying that their roles had changed, e.g. they were no longer working for the Commission (DG Env, DG RTD), or no longer working on the same policy area as when they previously engaged with MAGIC (DG Env). In a later interview, EG from DG DevCo commented on how staff turnover and frequent rotation between posts within the Commission make it difficult for individuals to find time to learn and to maintain relationships with research projects such as this: "*We are so mobile especially in DevCo, people rotate in delegations. … But it would be a dream to have one person following from A to B because that person moves*" (EG). Other invitees declined as the topic was not their field of expertise (DG DevCo). Some Commission officials (Secretariat General, DG DevCo) said they were unable to attend due to the proximity of the end of the year, and because being busy with preparations for the new Commission. Some of those unable to participate asked to be kept informed of future events and project outputs.

During the event it became evident that some participants from different DGs knew each other, possibly due to past roles or to joint-working. Having a variety of people from different organisations was seen as useful by some attendees: one participant from DG DevCo said in a later interview that "*MAGIC did well to get different DGs together in one room because that doesn't happen very often"* (EG). Another participant wrote in the feedback form that it was "*interesting to hear the views of the relevant Commission DGs about this approach and the outcomes [of the] MAGIC project"* (AH). Another attendee from DG Agri praised the group dynamics (HF). However, the mix of people from different organisations may have impeded discussions to some extent; BD from DG Clima said that they selfcensored due to internal frictions, and that junior staff can be nervous to speak in front of more senior staff. Another attendee from DG DevCo said in a later interview that the researchers should be clearer in their aims with bringing the different DGs together in one meeting (EG). In terms of the different organisations represented, when asked in a feedback form who else should have attended, AH wrote "*I think your list includes already the colleagues I have had in mind."* In their feedback form, DW (DG Env) noted that there was no one representing DG Sante, and advised researchers to engage with them, as they are leading the Farm to Fork initiative. Several people from DG Sante had been invited to the seminar, who were either suggested by DW and PW (from DG RTD) or had been identified on the DG Sante's organisational chart.

The Parliament breakfast in January 2020 was hosted by a MEP who had previously been invited but unable to attend the November 2019 seminar. This event had similar aims to the seminar in November 2019, by considering a different group of stakeholders. The meeting was attended by 12 people in addition to the hosting MEP and their 2 assistants. Several of the attendees were MEPs and their assistants serving on the Parliament's Agri committee. There was also an attendee who worked in DG Agri, and one from DG RTD. Invitations were sent by the hosting MEP and their team, to whom researchers sent suggestions of people linked with decision-making or lobbying for sustainable agriculture. These included: MEPs (EP Agri Committee and Envi Committee), Commissioners for DG Clima, DG Agri, DG Env, DG Ener, DG DevCo, members of DG Agri (Directorates B2 and C), DG RTD (directorates C3 and C1), DG Env (directorate F1), and think tanks, NGOs and lobby groups.

In June 2020, researchers at the James Hutton Institute hosted an online seminar for the European Environment Agency, building on the materials presented at the seminar in November 2019. This was a request from members of the EEA who had been unable to attend the November seminar, and they forwarded the invitation to other colleagues. The researchers' aims for this event were similar to those of the previous two events in November 2019 and January 2020, with the expectation that people's views and responses might be different as they work in a different institution. In addition to the aims outlined for the November 2019 seminar, there was an added objective of encouraging an increased focus on the links between EU environmental, development and trade policies. Finally, researchers aimed to learn more about how the EEA and the Commission work together, what information is seen as salient and credible, and how the findings presented could be utilised in a policy process.

There were eight attendees: six people from the EEA, one from a University and one from a think tank. Some but not all attendees had prior knowledge of the project. Researchers' presentations were followed by questions and a discussion with participants. Discussion topics included the data used for SMA; links between topics discussed in MAGIC (such as externalisation of environmental pressures and interconnections between systems) and the work carried out at the EEA; whether the method can consider the evolution of policies and their impact over time, allowing to understand a policy's 'direction of travel' and the challenge of linking SMA to a specific policy instrument; the differences between SMA and life cycle analysis; and how SMA can support policymaking and implementation. After the webinar one person sent an email with further questions for discussion, and another person followed up with a phone call with one of the researchers to discuss in more depth some of the topics presented.

Finally, from April-June 2020, a researcher interviewed people who had taken part in the different MAGIC engagement events. Four interviews were conducted with people from four different European agencies or Commission directorates. All four had taken part in at least one MAGIC event, and three of them had participated in several events throughout the two cycles of MAGIC. The four participants between them were able to reflect and comment on all the events described in this section. Interviewees reflected on the stakeholders that could be engaged in this kind of project. EG (DG DevCo) talked about the need to engage the Parliament and its relevant Committees and Member States, to make the research more policy applicable. This interviewee also advised researchers to find an MEP to champion the project, and suggested that the way for the project to achieve impact is through the European Parliament and its committees: "*I would always be in favour to expose in a simple…in a simplified way for example, the Scottish MEPS …to say this was the conclusion of the research, this is how it's applicable from a policy framing point of view. And this is what we want the policy leaders to know and to be cognisant of*" (EG, DG DevCo). Researchers had already engaged with MEPs at the Parliament breakfast meeting mentioned above, about which this interviewee may not have been aware. Representatives from Council of Europe, and other institutions like the Committee of the Regions were not contacted. In terms of representing expertise on policies relevant to the WEFE nexus, there were some gaps, such as DG Sante and DG Env, as highlighted above. However, given that those who did participate suggested energy, food and agriculture, food security and climate change as policy areas where the MAGIC approach could be useful, the relevant people participated in the QST cycle.

3.2 QST Stage 1: Identify key themes for the story selected

The first stage of the QST cycle built on the previous QST cycle described in D5.5 (Matthews et al. 2018) that considered whether the CAP objectives of economic competitiveness and delivery of public goods were in tension. The previous cycle concluded that EU agriculture's dependence on external resources could increase competitiveness whilst undermining the provision of public environmental goods borders of the EU; and that EU farming systems are still largely driven by the level of inputs, meaning more intensive systems tended to correlate with more pressure on the biosphere. The analyses also confirmed the importance of linking pressures from farming systems to their environmental context and the need to consider intensity, extents and emissions. Although the research team believed the data analyses suggested that the pursuit of competitiveness and delivery of public goods are in tension, stakeholders who participated in a 'closing the loop' workshop were not necessarily convinced.

As discussed in Section 1.1.1, this QST cycle was implemented to explore the idea of how the EU was progressing towards SDG2 (using QST in diagnostic mode) and the role of policies regarding the WEFE nexus in helping with this progress. As part of step 1 in the QST cycle (*Identify key themes relevant to the nexus and policy*), we considered which actors and institutions were relevant to delivery of SDG2 at the EU level and from here, the story (or stories) to illustrate using the QST cycle. The PNS approach (Section 1.2.1), taking an explicitly progressive, normative and inclusive perspective on knowledge generation and use, means that this stage was also about understanding how issues are recognised as 'concerns' by institutional arrangements; where there are conflicts or differences in how concerns are recognised as salient for policy and what constitutes an evidence base for these policy concerns.

The introduction has demonstrated the importance of taking a systemic approach to delivering the SDGs and the evolution of the CAP from supporting agricultural production, to utilising the CAP to achieve a variety of economic, environmental, and social objectives. Recent communications (e.g. (European Commission 2020b) continue to assert that *"Sustainability is at the heart of CAP… In the future CAP, we'll go even further!"* These were also themes emerging from analysis of further interviews and document analyses conducted for phase 2 regarding the EU role in delivery of the SDGs and the role of CAP and SDG2 as a nexus for linking Water, Energy, Food and the Environment (including the circular economy) policy domains. However, our findings suggest that sustainability or complexity are probably more useful framings than the WEFE nexus per se for actors within the EU institutions, given that the idea of the 'nexus' was not often used in policy discussions. Our interviews confirmed that taking even a partial perspective on complex systemic interactions within and between SDGs would be problematic, both in terms of content and navigating the interactions of different DGs within the Commission, and wider stakeholders' interests.

The first phase of QST requires an interwoven analysis of actors within institutions. Our focus was on the role of EU institutions in progressing the SDGs, particularly SDG2. For example, EU policymaking is important for sustainable agriculture as the EU sets environmental standards through its legislation and co-finances most of the Member States' agricultural spending (European Court of Auditors 2020). DG representatives suggested that the EU were front runners in developing the SDGs and that the EU shows leadership within the UN. Therefore, the main actors for QST were those actors involved in governing the SDG process, including the tripartite governance structure of the Council, the Parliament and the Commission. The Commission are the administrators of public policy, identified as the main users of scientific evidence for policymaking within this tripartite. Within the Commission, our interviews confirmed that the cabinet for the Vice President has responsibility for sustainable development, which helps makes sure that sustainable development is not an 'add-on'. The Secretariat General helps to coordinate delivery as well as having responsibility for the Multi-Annual Financial Framework, which sets budgets that in turn constrain or enable policy development and delivery. Unfortunately, we were unable to find anyone willing to be interviewed about these leadership and coordination roles to inform this stage of our QST.

The JRC interviewee drew our attention to an interservice group involving all 28 DGs that was convened to develop a Reflection Paper Towards a sustainable Europe by 2030 (European Commission 2019a) and another interviewee (JR) explained the role of the Multi-Stakeholder Platform on SDGs in authoring the paper. The focus on the SDGs seems to have reinvigorated the focus on policy coherence within the Commission, such that DG Agri are "*committed to work together with other stakeholders and other DGs, the European Environmental Agency, the Joint Research Centre*" (SD, DG Agri). The DG Agri interviewee also confirmed how the supporting agency, Eurostat, has repurposed its sustainable development indicators to help track delivery of the SDGs, whilst all policy development processes must consider the SDGs as part of their impact assessment processes. Therefore, the CAP impact assessment publications were assessed as part of understanding the salient themes and processes for this stage (European Commission 2018b).

Our analysis confirmed that CAP was important as a nexus policy. There seems to be a process of CAP becoming broader, both in terms of its reach across the economic, social and environmental pillars of sustainability, and in terms of its reach beyond the 'farm gate' into food processing and health. Documents, interview and fieldnote data support this presentation of the CAP becoming increasingly focused on sustainability, particularly environmental/climate improvement, and that good progress is being made. These changes meant that DG Agri was increasingly interacting with DG Env, DG Clima and DG Sante for example. Analysis also noted the role of the EU in international relations, and the importance of how the EU interacts with the UN.

Our analysis also confirmed the importance of CAP to several SDGs as well as being central to SDG2. The connectivity of CAP to several policy domains and sustainability issues can be seen in figure 8, an infographic from the EC. Taking a WEFE nexus perspective, the Commission suggests that CAP supports SDGs associated with water, environment, energy and sustainable production and consumption, which has evolved to include the desire to have a more circular economy, promoting reuse of previously discarded materials. The same evaluation is found in the impact assessment of the proposed CAP post 2020 (European Commission 2018b) whereby the proposed operational objectives of CAP are presented as relevant to nearly all of the SDGs.

Figure 9: European Commission view of connections between CAP and SDGs

Beyond the Commission and the policy DGs, other actors are involved in governing and steering the delivery of the SDGS. Non-state actors, not least those represented in the Multi-Stakeholder Platform on SDGs, are important. NGOs were important in lobbying for transformation and holding the EU institutions to account, and the media are an important actor in how sustainable development policies are perceived. The interviews also noted the role of the private sector, with contrasting views regarding the potential of the private sector to progress the SDGs through sustainable finance and the power of private interests to block required change. Our analysis of interviews and fieldnotes highlighted the potential 'blocking' role that the Parliament and Council could play in terms of vetoing more ambitious sustainability policies. Finally, Member States are important as members of the EU and the UN, making the role of the Commission complicated as delivery of the SDGs is an area of 'mixed competency'.

In the reflection paper, the EU is presented as a front runner in sustainable development, and hence "*exceptionally well-positioned to lead"* (European Commission 2019a). Whilst the adoption of the SDGs has highlighted the need for everyone everywhere to contribute to the goals, the focus is still primarily on the 'external dimension' such as development aid and trade (European Parliament 2019). The interviews and fieldnotes support the observations from document analysis that much of the existing implementation of the SDGs has focused on the EU's role in international relations. This was explained through having a 'compulsory decision' to explicitly align the EU external policies with the SDGs and the fact that development and trade are central to the mandate, and competency, of the EU institutions. Finally, the way to deliver the SDGs is presented as ensuring policy coherence between existing EU policies and actions, rather than taking new approaches, because policies, particularly the CAP, had been mainstreaming sustainability since the early 2000s. This suggests that the Commission held a position that SDGs with the EU can best be addressed by incremental refocusing of an existing approach to sustainable development: "*The EU is already in a good way, in the right path to achieve the SDGs, because a lot of policies have been already adopted in the past for the sustainable development. And there are already some levels that can be used to exploit synergies*" (KS, JRC).

Therefore, the main themes being articulated from the Commission regarding the story underpinning the D5.1 QST cycle were:

- The EU Sustainability goals evolved from those underpinning the EU 2020 agenda and the supporting 7th Environmental Action Programme, to supporting the UN2030 Agenda and its 17 SDGs;

- The EU is a world-leader in sustainability and can provide leadership on delivery of the SDGs;
- The focus is on both external international relations (trade and development support) and domestic policy implementation;
- No radical change to EU policymaking is required beyond continuing to practice policy coherence;
- CAP is a nexus policy, influencing several SDGs involving water, climate and the environment; and
- CAP operates within the EU boundaries but is consistent with EU development policies, supporting other countries to achieve the SDGs.

Identification of these themes represent an important result from the first phase of QST, highlighting a range of issues and assumptions that it could be productive to examine with quantitative data. It is important to note that even without directly discussing themes with stakeholders, our analysis illustrated that these stories were contested. Interviews, fieldnotes and document analysis show that the positive progress towards the SDGs is disputed by non-DG participants, and policy coherence was important but not yet fully operationalised. The Commission has been criticised for failure to have a clear and coherent strategy about how the SDGs will be delivered European Parliament (2019); (European Economic and Social Committee 2018). At the start of the QST cycle, there was no visible SDG implementation strategy beyond a list of existing EU policies and actions brigaded under each SDG. Our interviews helped us understand this, explaining it would be up to the 'new Commission' to decide how to replace the EU Agenda 2020 and how to respond to the UN Agenda 2030. These insights illustrated a tension between delivering the agreed and legitimate programme of the Juncker administration and evolving to respond to the new policy agenda of the SDGs. The lack of a new strategy might also be explained by the fact that the weighting of sustainable development priorities is contested - with different interviewees arguing that the Commission's approach to the SDGs was skewed to socio-economic (JR, advocacy NGO) or environmental aspects (KS, JRC). Our data also suggested different views on whether fundamental transformation was required, contrasting a political perspective (JR, advocacy NGO) with a focus on technical institutional responses by KS (JRC) and SD (DG Agri). These insights mean that the SDGs are contested, with different actors and organisations having different priorities and entry points to the EU's delivery of the SDGs.

A review of relevant policy documents highlighted that there are documented issues with policy coherence. Recent water and biodiversity 'fitness' tests (European Commission 2016, 2019b) highlight that lack of progress on these directives is partly due to inadequate integration of water or biodiversity objectives in policy areas such as agriculture, energy and housing. These tensions were reflected in the interview and fieldnote data, where JR (advocacy NGO) suggests "*for the different DGs they are not always working together. They are often focused on one thing*." Others from within the Commission were more positive about coherence, there are hints that this is a still a work-in -progress: "P*olicy coherence for development has really started … and this is something also where we are working…for the next Commission to improve*" (SD, DG Agri). They go onto describe the interservice processes on the SDGs as: "…*another layer that the Secretariat General chairs"* and notes *"the reflection paper was a bit top down, no?*" Our experience of trying to interview officials about the institutional arrangements for the SDGs also reflected a tension in roles and responsibilities – the memo on SDG interviews notes that the Secretariat General staff redirected our interview requests to sectoral DGs (e.g. DG Agri, DG DevCo).

Our analysis, building on the presentation of relevant policies by the Commission (at the level of the goal and the targets) found that SDG2 has a narrow focus on agriculture, water and environment. There are relative gaps regarding energy use especially beyond standard GHG emissions; and lack of attention to the circular (bio) economy, despite proposed new CAP 2020 objectives. This was also highlighted in other evaluations. For example, the current CAP focus on 'climate action' which is primarily regarding mitigation of GHGs (nitrous oxide from fertilisers, enteric methane from livestock digestive processes, and emissions from manure) rather than having a focus on renewable sources or energy efficiency in agricultural systems (Pe'er, Lakner et al., 2017). The CAP fitness check (Pe'er, Lakner et al., 2017) did not address the circular economy at all, illustrating how the concept has only recently (since 2017) gained traction in EU policymaking (Kovacic, Strand, and Völker 2019). The fitness check concluded that the CAP contributes to SDGs concerning poverty and food security (SDGs1, 2) in the EU, whereas the impacts outside the Union are varied. Regarding environmental questions (SDGs 6 and 15), the CAP has led to local improvements but overall, the greening approach and other environmental measures have yielded limited results. Some gaps also remain in the measures addressing climate change mitigation (SDG 13) and the study suggests that measures to make more progress towards the decoupling of emissions from production should be improved[7]. This reflects the latest trends (Eurostat 2019) where SDG 13 and SDG 15 have made little to moderate progress, whilst SDG2 is ranked 7th in terms of progress over time. This is mainly due to positive trends for nutrition and health, whereas sustainable agriculture had a more mixed performance (with negative results for farmland birds and ammonia emissions). Interview data also confirmed this critical reading of CAP performance: *"Yeah [the CAP] that's not only bad for the environment it's also bad for the farmers, small farmers, for the whole urban and rural planning. I mean I think it's bad for everything. I don't know why that's still there. Only for agro-industry, I mean amongst the buyers they are happy. But all the rest is losing in this"* (JR, advocacy NGO).

In common with most studies of complex and adaptive governance, institutional boundary definition can be challenging. An important aspect of both QST and EU institutional arrangements for sustainability is the cross-scale interactions (from global to local). For phase one of QST, this entails understanding the actors and nested institutional arrangements involved in multi-level governance[8]. For the SDGS, or SDG2, the +1 level is the UN's global agenda, but this only exists because 193 member states signed up to the 2030 Agenda. The entry point for analysis is the EU but this is already a complex ecosystem of institutions which are influenced by global or transnational and Member State interests. The -1 level is the 28 Member States (which became 27 due to Brexit during the QST cycle), but the Member States consist of different regions (e.g. NUTS2 regions) which have heterogenous environmental and social configurations. Furthermore, "*sometimes it's a bit complicated for the Commission to position itself, the Commission I mean, as an institution, because when it comes to SDGs because it's an area of mixed competency and…in general the member states are members of the United Nations*." (SD, DG Agri). MAGIC is about adaptive governance **in** complexity – and the multi-level governance is an important feature of such complexity.

Finally, taking account of time is also a common challenge for adaptive complex systems analysis. The findings presented in Section 3.4 reflect past policy implementation, i.e. the attainment or otherwise of the 2014-2020 CAP objectives or the objectives of the other nexus policies. However, the actor we engaged to form our Mixed Teams (see Section 3.1) may not have been in post or had any influence on either designing or implementing our five nexus policies. Interaction with actors therefore focus on policy design or implementation in the future. Our QST had to be mindful of the policy positions that explain the pressures being quantified and understanding the context in which the SMA results would be interpreted as salient for current and future policymaking. More generically, institutions do evolve, albeit incrementally. For example, interview data and fieldnotes suggest that DG Agri is trying to embrace the complexity of a systemic approach to CAP, despite the

[7] Noting that outdoor agriculture using soil is very unlikely to ever be GHG emissions free.

[8] We recognise that polycentricity is also an integral part of sustainability governance in the EU, but this was not an explicit lens in our approach.

constraints imposed by the Juncker Commission focused on 'stability and simplicity'. During the implementation of QST, there have been many developments in terms of the wider context. The 2019 elections have seen a change in the Commission and a change in the political profile of the Parliament and its supporting councils. This has delayed some policy development (for example, the next CAP has been postponed for two years) and provided new overarching narratives about the purpose of the EU and therefore the Commission, as articulated through the Green Deal and its supporting strategies (European Commission 2019d). Consequently, the analysis has been done at a time when many other reports and actors have been considering similar issues. This is revisited in Section 4.

3.3 QST Stage 2: Deciding what to represent in societal metabolism accounting

These decisions were covered in Section 2.2 as it became repetitive to try to separate how choices were made with what choices were finally implemented.

3.4 QST Stages 3 & 4: Results of MuSIASEM analysis

The QST cycle, presented in Section 1.2.2, requires the semantic aspects of storytelling e.g. identification of the main actors involved (reported in Section 3.1), and the main stories to be told (reported in Section 3.2) with the formalism of societal metabolism accounting. This section selects some of the metrics generated from the MuSIASEM processor to consider to what extent EU agricultural systems can be seen to be biophysically feasible or socio-economically viable. This allows an analysis of whether current outcomes match the desired outcomes from CAP and other policies (WFD, Natura 2000) and whether the outcomes suggest that the SDG2, particularly the target for sustainable agriculture (2.4, see Table 1), can be delivered under current arrangements. This section presents the component results with interpretation which are then synthesised and discussed in the context of the overall questions in Section 4.1 (Sustainable agriculture: Is the status quo desirable?) and Section 4.3 (Lessons learnt about SDG2 and the UN 2030 Agenda).

The results of MuSIASEM's application are presented as follows:

- A characterisation of the EU agricultural production systems, going further than the standard evaluation (e.g. as illustrated within the Common Monitoring and Evaluation Framework Dashboard (European Commission 2017b)) by decomposing the results into either farm types and/or down to FADN regions.
- Examples of environmental pressures and impacts across the EU FADN regions by farm types, focussed on water, soil and biodiversity, including embodied water from outside the EU.
- Examples of socio-economic pressures across the EU FADN region by farm types, focussed on incomes and subsidies.
- Examples of supply systems that draw attention to the flows into and out of the EU agricultural production systems, focussed on trade and simulations of reinternalization of land or labour.

As outlined in Section 2.4, the benefit and challenge of a societal metabolism approach is the flexibility of the accounting framework, allowing many different combinations of variables. Therefore, the sections below are both detailed yet remain partial in their coverage. Examples have been selected to respond to the focus of this QST cycle but remain examples, rather than a full coverage of all possible variables.

3.4.1 EU Agricultural Production Systems

This section presents a high-level characterisation of EU farming systems informed by the ideas of societal metabolism accounting. That is, it is concerned with funds, flows and externalisation, extents and intensities of resource use and linking across scales. The first part presents an overview of agricultural commodity flows using FADN farmtypes and member states (Section 3.4.1.1). Then the funds that underpin the flows are presented in terms of land (Section 3.4.1.2), labour (Section 3.4.1.3) and other capital (Section 3.4.1.4). A further characterisation of the funds is also undertaken – the degree of regional specialisation (Section 3.4.1.5). The section concludes by noting the relative importance of agricultural production systems in conventional economic terms (gross value added – Section 3.4.1.6) and the relative magnitudes of CAP funding mechanisms (Section 3.4.1.7).

In terms of policy, this kind of analysis serves to ground any interpretation of policy narratives in the biophysical and socio-economic realities of how the system is, rather than how we would like the system to be.

3.4.1.1 Flows of agricultural commodities

The focus here is on characterising the flows of provisioning services generated by the agricultural production systems of the EU. In terms of SDG2, ensuring access to supplies of agricultural within the EU has been a key objective since the Treaty of Rome (1957) with clear memories of rationing and hunger during, and in the aftermath of, the Second World War.

Figure 10 to Figure 15 show the mix of farm types that are delivering agricultural commodities and the countries with such farm types present. The figures use tonnes of commodity (extents) to identify the largest flows. Smaller areas or systems of production are likely important locally or to individual member states but the concern here is with a pan-EU perspective to assess the coherence of policies at a macroscale. The financial value of these flows will of course be very different since the value per tonne of commodities is so different. This configuration highlights the production systems (farm types) and locations associated with the bulk of EU food production. This sets up discussion of the coherence of the policy framework influencing what is produced, how it is produced and the undesirable consequences of the EU's system of food production.

Looking across the figures it is apparent that specialist production systems dominate in terms of the generation of commodities. Note that for fruit and vegetables, the diversity of systems in Figure 11 hides that when fruit is considered alone, it is dominated by the specialist orchard and fruit farm type and vegetables by specialist other field crops and secondarily by specialist horticulture. For livestock production systems granivores are particularly concentrated, perhaps reflecting that such enterprises have been less supported by CAP and are dominated by bigger specialist businesses with substantial infrastructures. Red meat is more diverse in terms of production systems with both intensive and extensive systems (especially for sheep and goats) and with red meat from dairy systems[9].

It is apparent that at a macro level there is a lack of mixing of crops and livestock, with any synergies or market diversification benefits being outweighed by the need for a broader range of management expertise and to maintain more on-farm infrastructure. The crop and livestock farm type is small, but individual businesses can often be large enough to have specialist production systems within the

[9] Livestock caveat – the tonnage values for granivore and red meat are based on livestock numbers on farm in terms of livestock units. The livestock tonnage values contain both the breeding animals (fund maintained over time) and the livestock sent for slaughter (the flow). The magnitudes are thus overestimated but this is mitigated since in most cases breeding stock will eventually end up in the food chain in some form.

overall business. The lack of cropping in more specialised livestock operations would seem to work against localised diversity of land use and against the wider spread use of organics production systems.

Geographically it is apparent that there is a degree of specialisation across EU, seen most clearly the in fruit and vegetables. From the figures there are indications of variations in productivity with some larger countries not as prominent as might be expected in any of the production systems (e.g. Romania). Systems like milk and granivores are widely present but are likely very different types of production system in specific locations.

Note that any assessment of the sustainability commodity flows in the EU needs to consider imports and exports (externalisation) as well as the within-Member States production presented above. Trade provides inputs to agricultural production, to food processing and substitutes/supplements to human food in Europe (see Section 3.4.4). The next sections consider the funds of resources being used to generate these commodity flows.

Prodcution in tonnes, total for 2014-17 by Member State and farm type

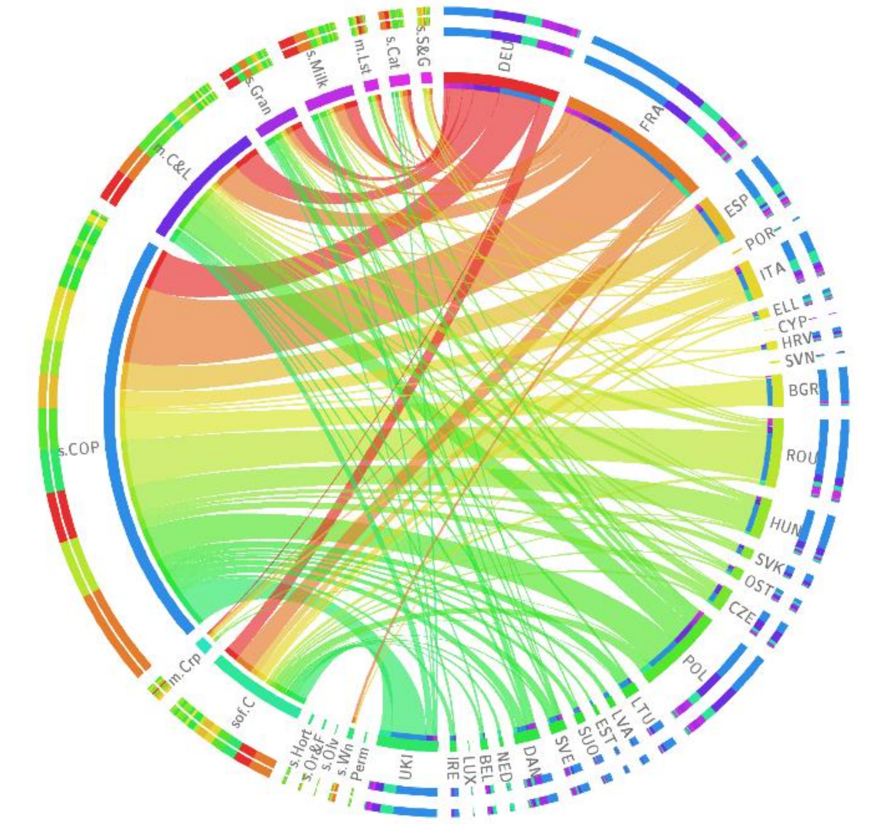

Figure 10 Cereals, oilseeds, and protein crops

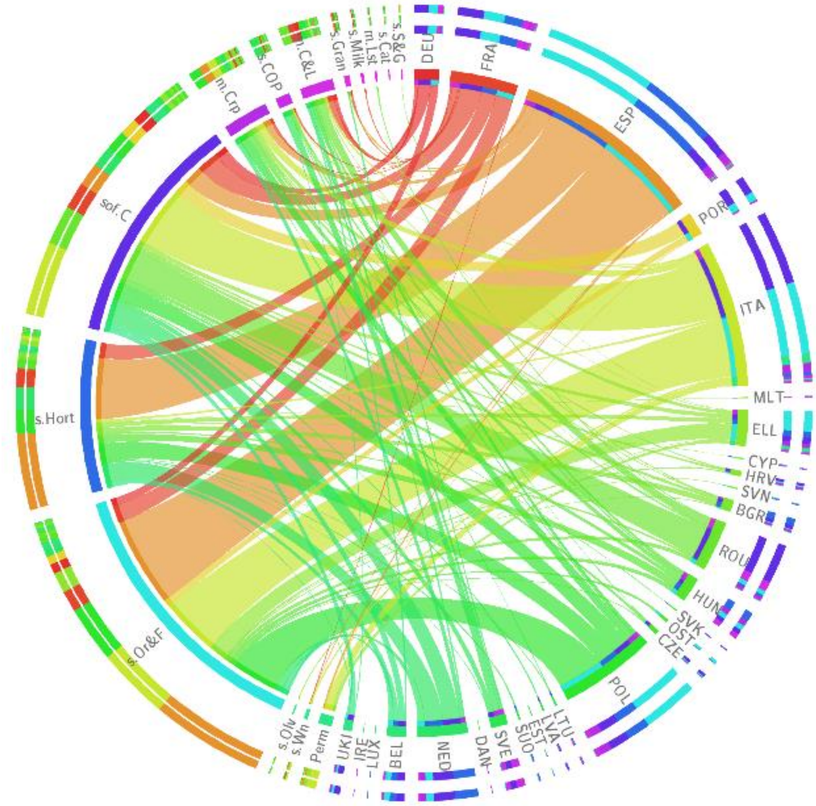

Figure 11: Fruit and vegetables

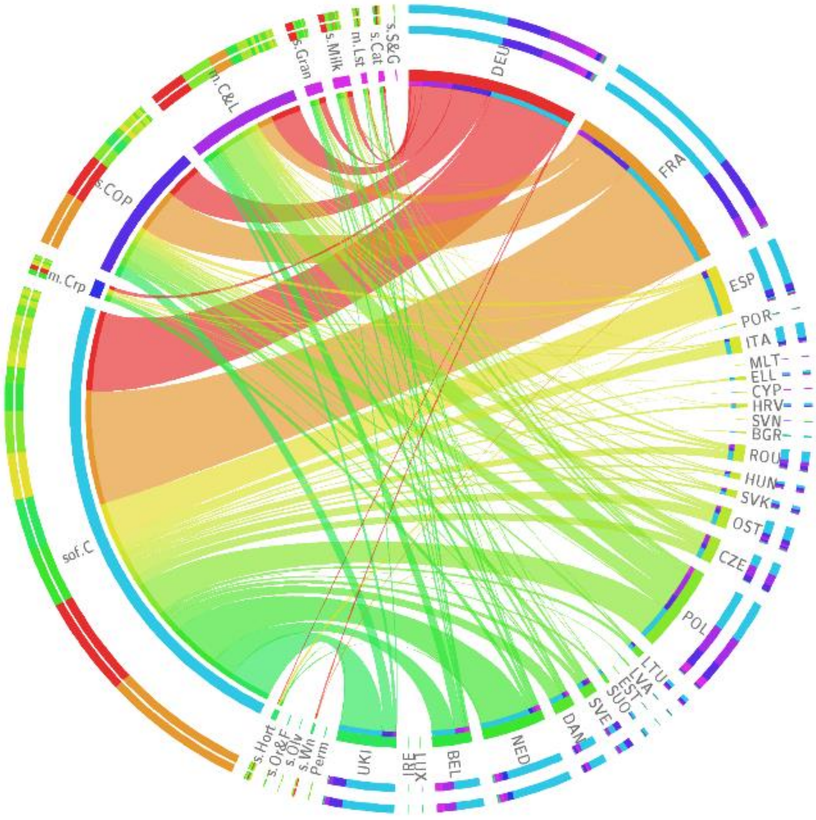

Figure 12: Potatoes and sugar beet

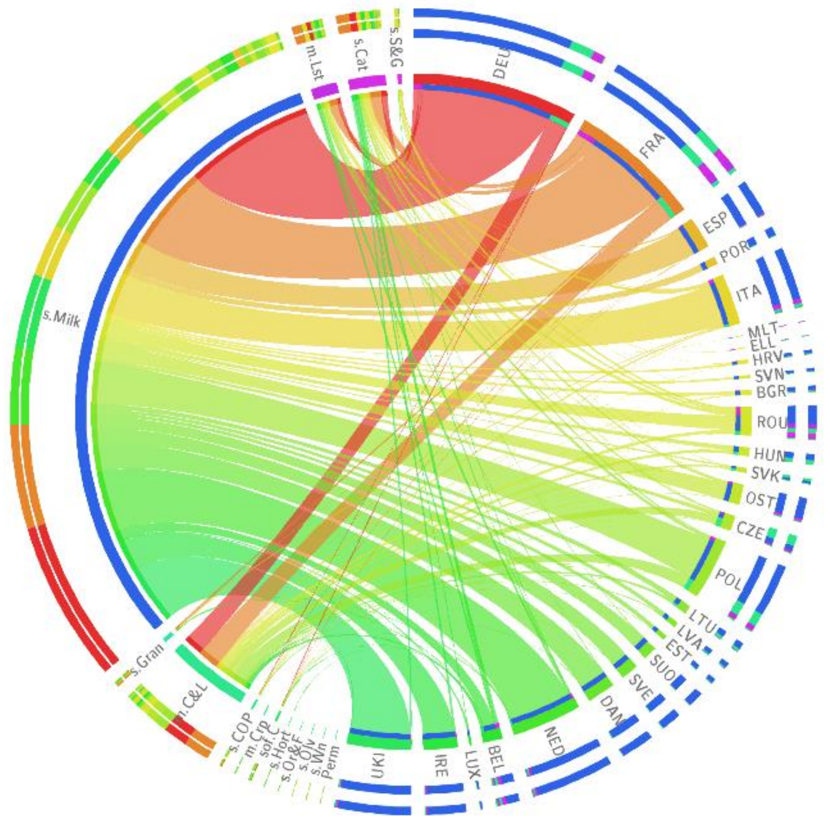

Figure 13: Milk

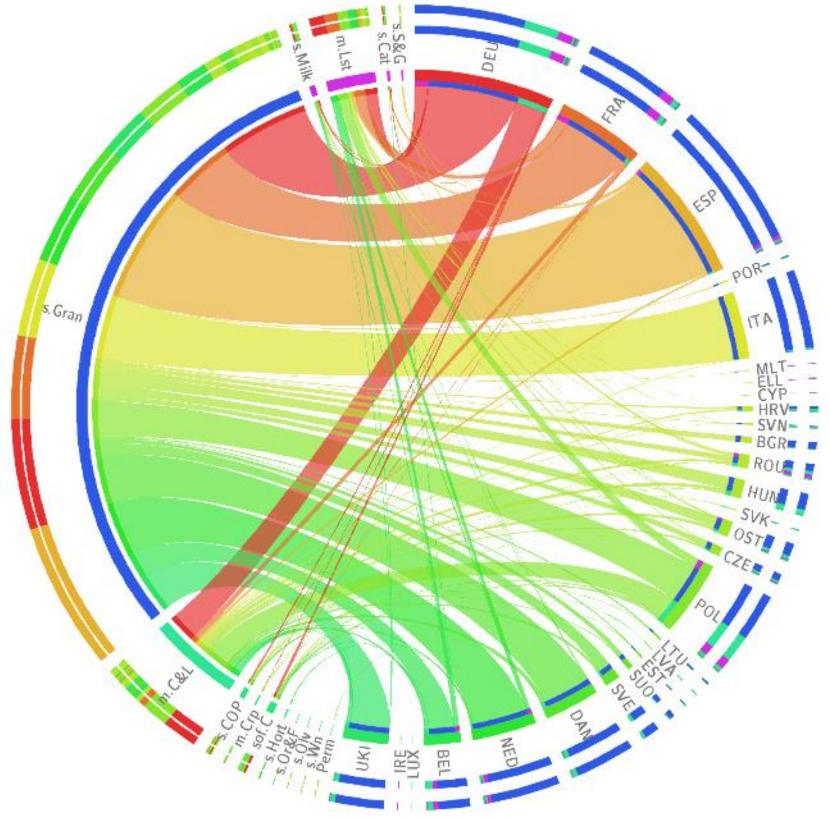

Figure 14:Granivore meat

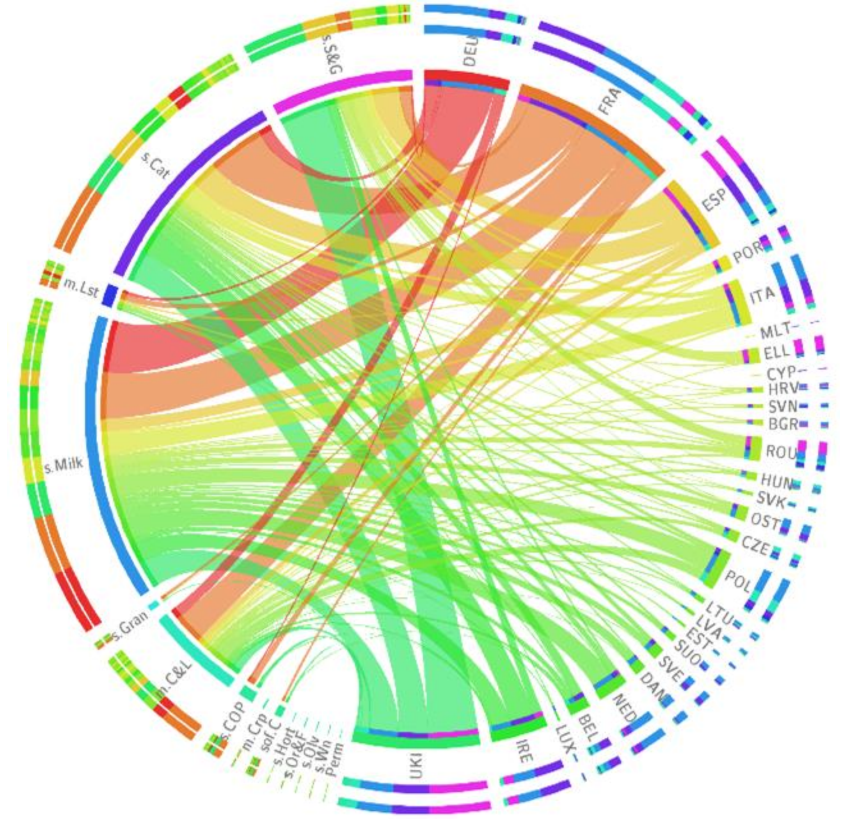

Figure 15: Red meat

3.4.1.2 Land

The flows or agricultural commodities above generate a demand for land as illustrated in Figure 16. The figure presents a breakdown of the EU utilised agricultural area (UAA) in 2017 by Member State and farm type. The figure thus highlights where the largest areas of agricultural are within the EU, and how land is used in terms production systems (the farm types). The figure highlights the relative extents of cropping and livestock-based systems in the EU, with specialist cereals, oil, seed and protein crop holdings having the largest single entry. It is worth noting the relatively small extent of holdings associated with fruit and vegetable and related commodity flow extents. The overall extents of each production system give an indication of the extent of pressures being exerted but also that individual Member States are dealing with very different mixes of production systems and pressures (the outer rings per Member State) with the inevitable challenges that this means for creating overarching policy frameworks that are both effective, non-discriminatory and locally acceptable.

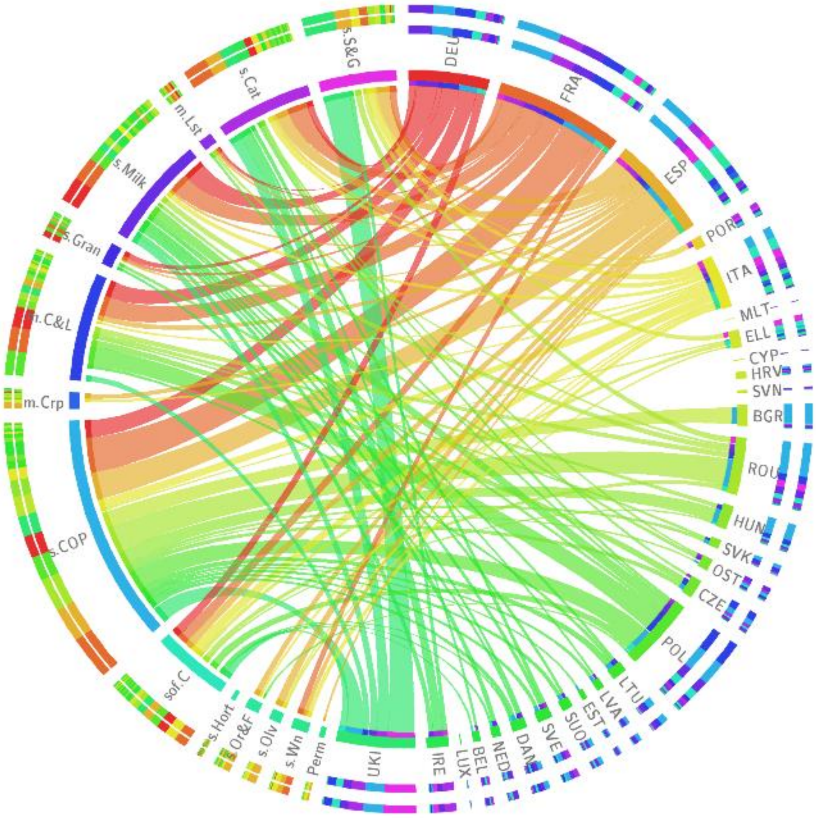

Figure 16: UAA 2017 - by Member State and farm type

The overall land take by agricultural production systems is also an indicator of the relative pressure that such systems exert. Figure 17 is a relationship map for the ratio of UAA to total land area for NUTS2 regions in 2017. Regions with increasingly orange tones have smaller proportions of land devoted to agriculture. The figure highlights that for much of the EU the proportion of all land that is included within the UAA is close to 50%, but with cases as high as 90% and others where forestry predominates having much lower UAA percentages. In terms of extent, agricultural land uses are thus a strong driver of sustainability outcomes for terrestrial and aquatic ecosystems in the EU. While there are areas with lower intensity and more extensive production systems, even here the degree of impact can be significant where natural ecosystems are potentially more susceptible to disturbance (e.g. in mountainous regions). It is in its land take and dependence on natural capitals that agriculture is most distinctively different from other sectors and why there needs to be specific policies to ensure that the funds associated with the generation of commodity flows are managed sustainably.

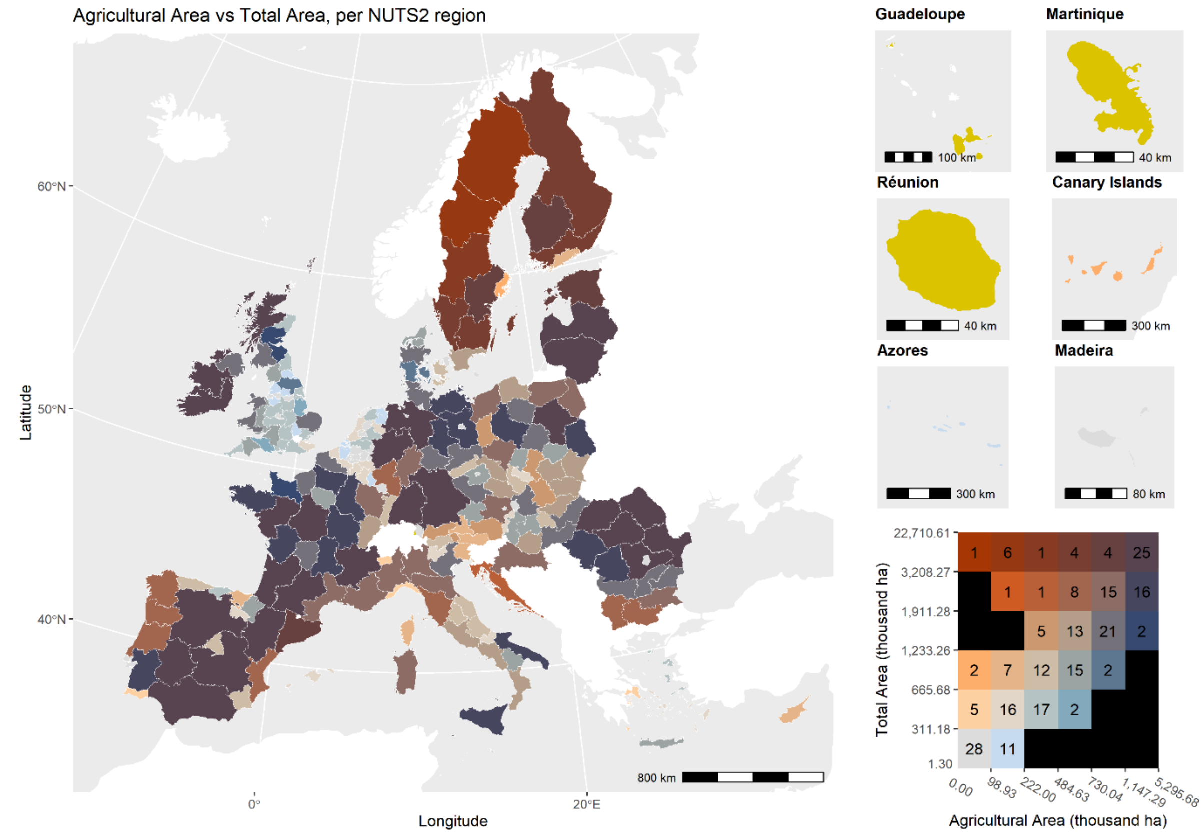

Figure 17: UAA vs all land in regions

3.4.1.3 Employment

Contrasting with the clear importance of agricultural production systems in terms of use of land, when employment is considered interpretations need to be more nuanced. The importance of agricultural production systems as a source of employment varies considerably across the regions of the EU. Figure 18 presents a relationship map between employment within agriculture and total regional employment. The figure highlights those regions with lower proportions of employment in agriculture (oranges) and those with larger proportions (blues). It should though be noted that only rarely (10 of 121) is the agricultural sector greater than 20% of the whole work force even in the most rural area, with a majority (61 of 121) less than 5%. Higher rates of employment in agriculture are also rarely associated with above average indicators of prosperity and wellbeing. What is distinct about agricultural production systems though is that most employment is of farm family labour (Figure 19) and their need for seasonal labour, particularly for production systems with higher labour demands such as horticulture, orchards and fruit, and field crops. The use of labour funds per Member State and farm type are shown in Figure 20.

Taken together these features present complex policy coherence and presentational challenges. Agricultural employment is now smaller than many other sectors that, in effect, no longer exist within the EU economies and agriculture continues to follow a historical tend in declining numbers. Yet labour remains a vital component of agricultural production systems, despite increasing use of mechanisation, and the flows of food commodities have a public good value in terms of food security as well as a private good value as an economic activity. This means the policy takes an interest in promoting agricultural employment despite the small numbers employed (extent) and the often poor returns per hour of work for those employed individuals (intensity).

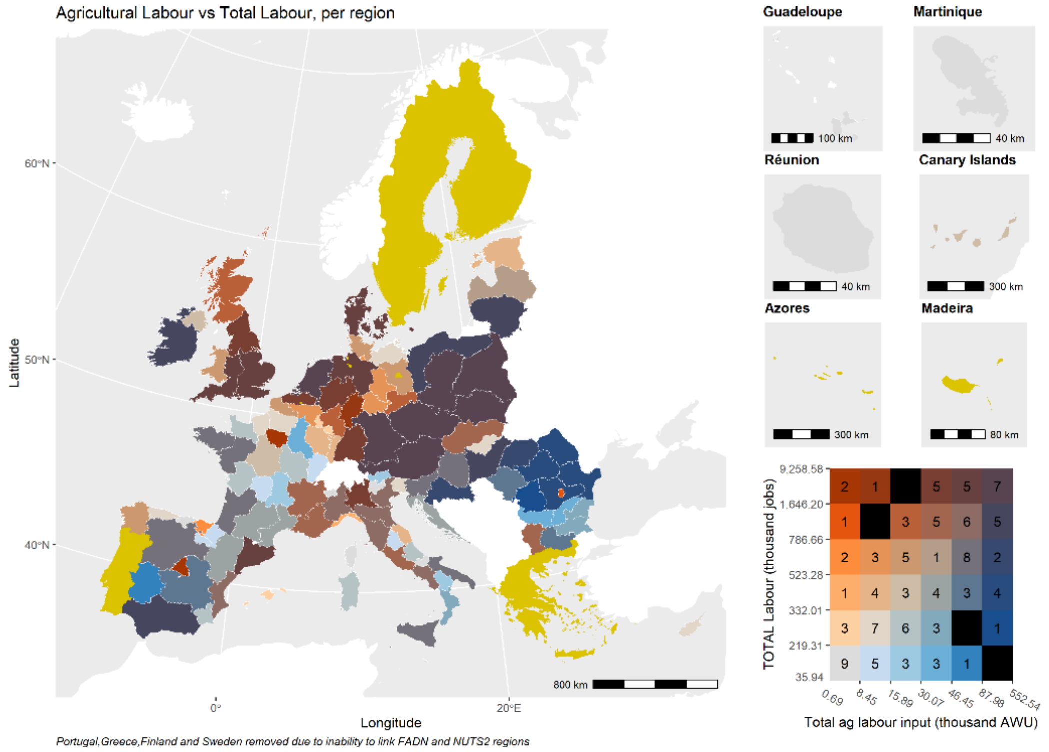

Figure 18: Agricultural vs. overall employment

The continuing presence of the 'family farm' is also seen as desirable within the EU as it is associated (at least rhetorically) with a basket of public and private benefits compared with farming systems e.g. in the USA. Yet such farms are recognised as being part of a disappearing 'squeezed middle', being replaced by a mix of larger corporate farms and smaller lifestyle units. Here the challenge is in squaring the desire for employment within family farms with the pressure from supply chain, retail and consumer expectations of low and preferably decreasing costs of food. Increased efficiency from such farms may not be rewarded by the market, and increased intensity of production may mean private gain at the expense of the loss of public goods. The niche of distinctive regional commodities (Denominazione di Origine Controllata and Appellation Controlee) can have benefits, but retaining or creating new land-based family businesses remains challenging.

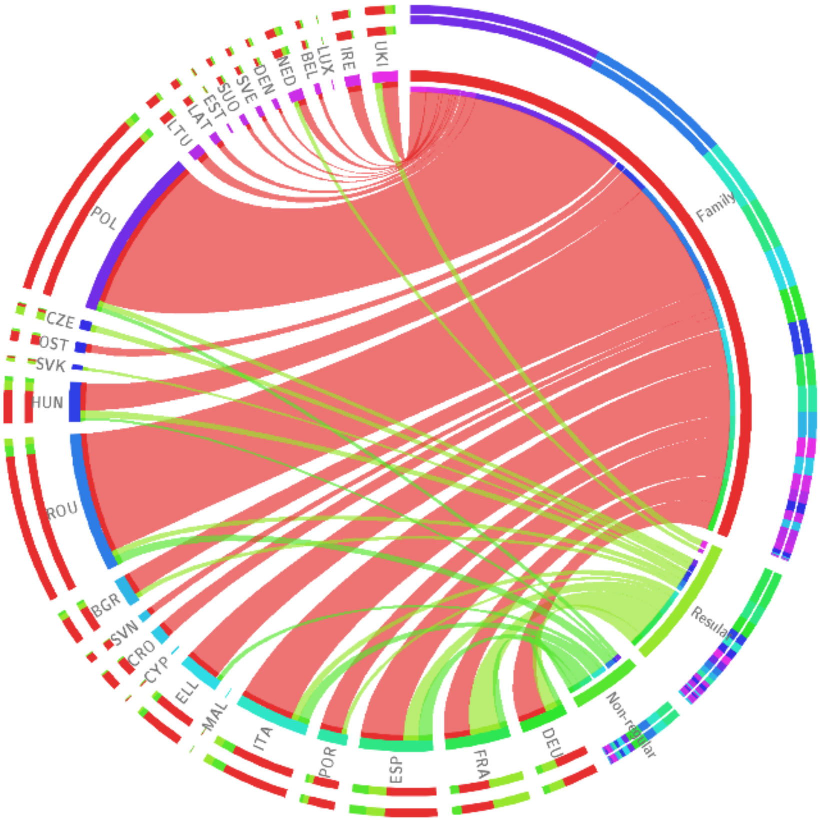

Figure 19: Labour types – 2013 AWU

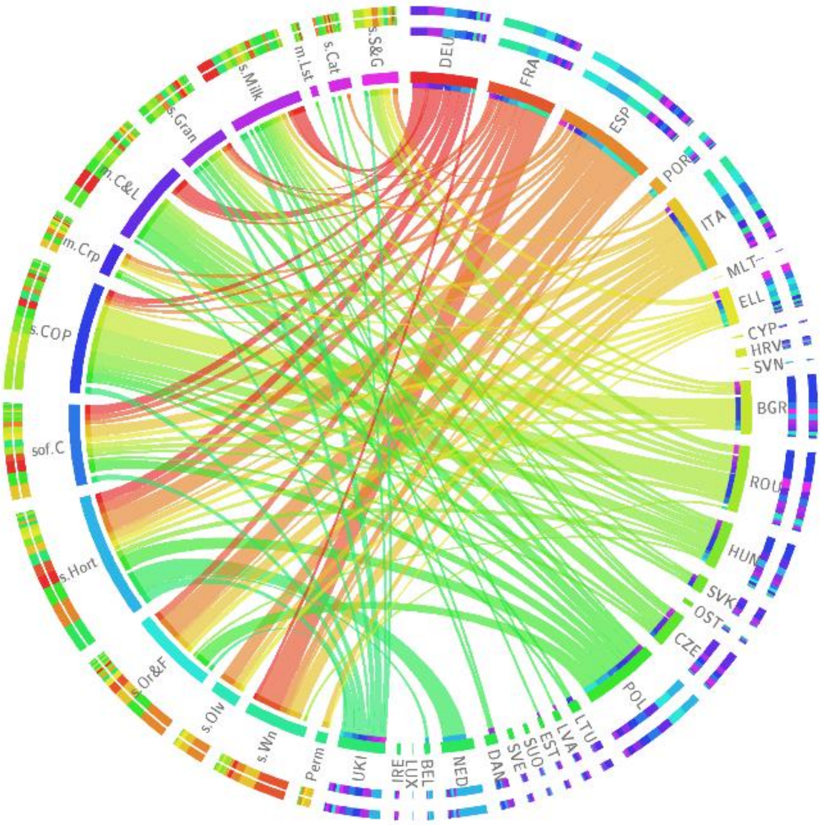

Figure 20: Hours of labour 2014-17 by Member State and farm type

3.4.1.4 Capital

For societal metabolism accounting of production systems, physical capital, in the form of machinery and buildings, is another key factor in understanding how flows are generated – with distinct contrasts within and between production systems. Such physical capitals are funds that need to be created and maintained over time, so can be viewed as overhead. Contrasting with other sectors, agricultural production systems can see very low rates of utilisation of such capitals, for example for crop-based systems machinery used only at harvest time or buildings used for seasonal housing of livestock. In this way it has long been argued that increasingly capital-intensive agriculture can become unviable (in financial terms the gross margin benefits are not ultimately reflected in higher net margins) (Georgescu-Roegen 1971; Giampietro 2018).

With the datasets available it was possible to make an assessment of the capital funds being used and to contrast between Member States and farm types (see Figure 21). The analysis combined data in FADN on machinery and buildings to set the fund size. Figure 21 highlights the relative levels of capital funds associated with different production systems (farm types). The figure highlights those sectors where more intensive production systems have become the norm e.g. dairy, and systems that overall have lower reliance on buildings and machinery e.g. cattle, sheep and goats. Within cropping-based systems, in contrast with land where specialist COP farm types were the most extensive, there is significant capital tied up in generating fruit, vegetables and other more specialist crops. For Member States, the contrast is between those like the Netherlands and Austria which feature more prominently than in the labour charts, and those such as Spain that make less use.

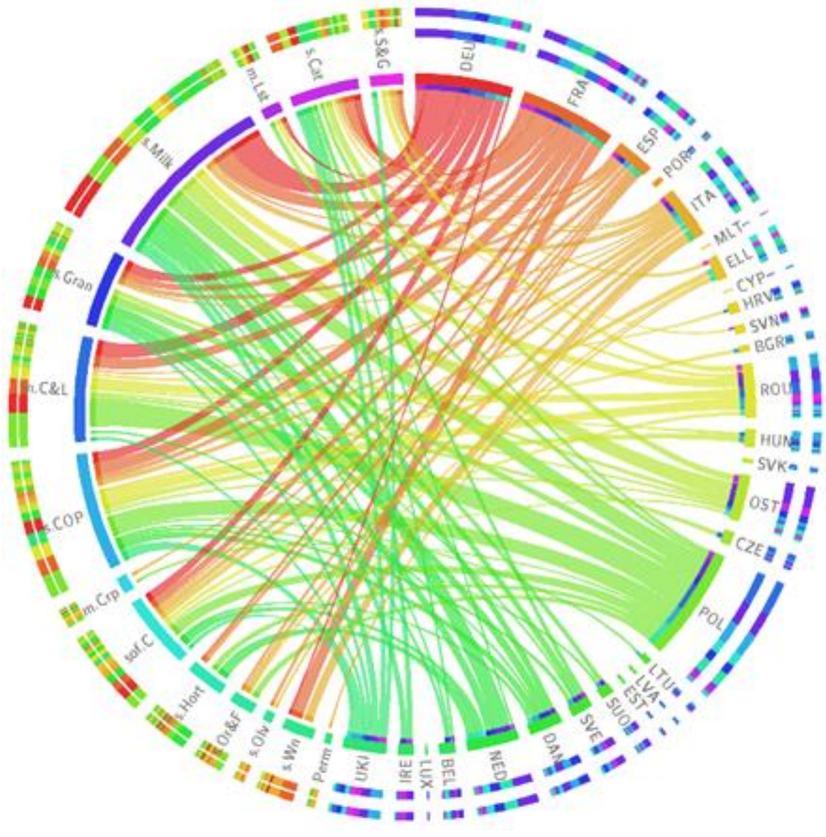

Figure 21: Capital - machinery and buildings value in € 2017

The farm business-based statistics on the use of such capital items may however seriously underestimate the fund of capital being used where the machinery is provided and used by third party contractors. Additionally, while this analysis has provided some insights into economic capital funds it would be highly desirable to characterise these funds in physical terms. For machinery, power capacity (kW) provides an energy-oriented metric, and this could potentially be derived from data in the Farm Structure Survey. Analysis of the materials embodied in machinery or buildings, and their longevity can also provide a better estimation of the draw of these items on other funds and this their sustainability implications. The analysis has also not considered the financial capital value of land, and how area-based payments from CAP can drive up the value of land, creating a variety of undesirable outcomes, both practical and presentational.

3.4.1.5 Specialisation and diversity

Having taken macro flow- and fund-oriented perspectives on EU agricultural production systems, it is now useful to change scales and focus on the diversity of agricultural production systems within the regions of the EU. Here the analysis is influenced by the ideas of resilience (Gunderson and Holling 2002) where specialisation, while economically rational, creates a lack of diversity that severely limits both the ability of systems to weather disruptions and their ability to change over time without instances of catastrophic collapse. Greater diversity of production systems may also generate a more diverse landscape, potentially with more ecological niches within the farmed landscape that can supplement those within the land beyond the UAA (see Section 3.4.1.2). Diversity of production systems means that the pressures associated with a production system may be buffered or limited in in extent.

Two analyses of diversity are presented: one using crop types (Figure 22) and a second using farm types (Figure 23). The cropping analysis is concerned with the prevalence of 'monoculture' associated with loss of biodiversity and which promoted initiatives such ecological focus areas and the three-crop-rule in CAP Greening. The farm type analysis extends this form of analysis to the mix of production systems present within regions. In both cases the figures present relationship maps for diversity and evenness. Diversity here is calculated using the Shannon H index – with the 'species' being the numbers of crops present or the numbers of farm types. Evenness is the Shannon E index with evenness measured in terms of area (area per crop or per farm type). Evenness has a maximum value of 1.0. The two measures provide complementary perspectives on the patterns of cropping and the mix of farm types present. While diversity may be present (multiple crops or farm types) if the area is still dominated by one crop or farm type then these are distinguished by a low evenness value.

Figure 22 presents the relationship map for crop diversity. The legend highlights the positive relationship between diversity and evenness with more regions on the diagonal but that the FADN regions have a wide variety of combinations of diversity and evenness. Geographically there is a clear distinction between southern and eastern areas with greater diversity but lower evenness, and north and western areas with lower diversity. This likely reflects the greater prevalence of grass pasture-based systems in the north and west, and the wider range of crops that are viable in the south and east, yet with specialisation meaning that such regions tend to have lower evenness values.

For diversity and evenness of farm types, Figure 23 highlights a similar pattern but with cases such as western Spain and Portugal with higher diversity of cropping but only within a limited number of farm types. Eastern Member States can see higher levels of farm type diversity but lower levels of evenness perhaps reflecting a predominance of a few production systems in area terms but with other production systems still present but being progressively replaced.

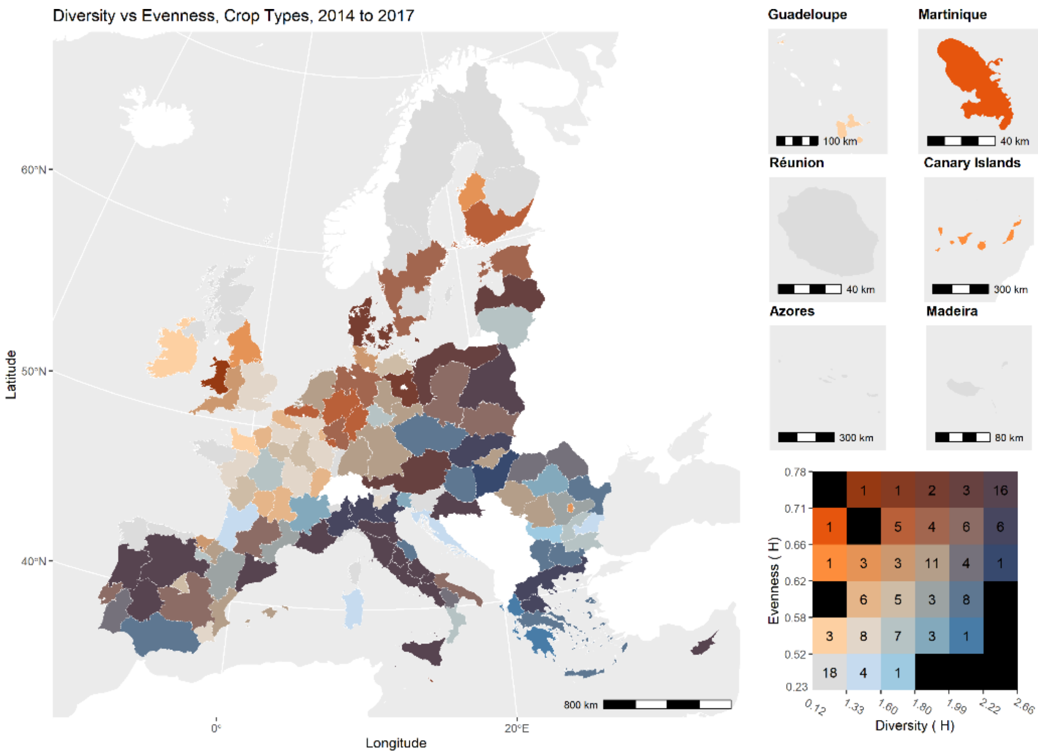

Figure 22: Diversity of cropping

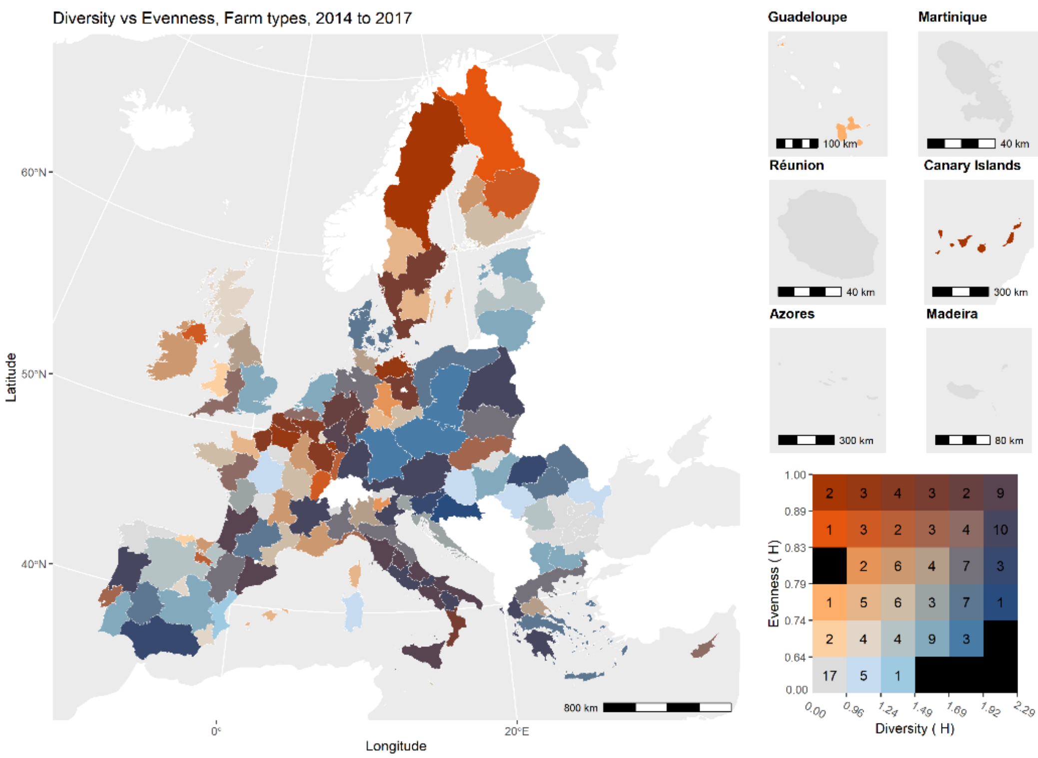

Figure 23: Diversity of farm types

3.4.1.6 Financial value of agricultural production systems within economies

Changing scales again, this analysis seeks to place financial outcomes of agricultural production system in a wider context. In societal metabolism terms, this is using an *external referent* to assess the significance of a fund or flow. In this case the focus is on the financial value generated by agricultural production systems (in terms of their gross value added, GVA). The external referent is the GVA for regional economies as a whole. As with employment, the financial value of agricultural production systems to local economies in more rural regions is used as justification for the continued use of financial support. What the relationship mapping in Figure 24 (agricultural production systems GVA vs all GVA for FADN regions) shows is that, in all cases at this geographic scale, the value of agricultural production systems is very small in financial terms. The map does however, highlight where, in relative terms, agriculture is more significant area (the lighter blue areas in the map). Yet the map also highlights that areas with higher agricultural GVA values can also have higher regional GVAs from other sectors (for example southern England, Benelux and north west Germany). Support for agricultural production systems in some regions may be desirable for economic resilience and rural development but is more difficult to justify where both the agricultural and other GVA values are high.

It is worth noting that GVA of agricultural production systems is small but that they form the basis of flows with much greater importance to economies – food processing, brewing and distilling, food retail and other services associated with food and drink (hospitality). This does raise the question, why if the flows generated by agricultural production systems are so significant, do they continue to generate so little value to their creators? The value of the funds they create in terms of landscape for tourism and recreation may also be significant. Here ease of substitution (externalisation via imports), power within supply chain relationships, the modernisation of economies to industrial and post-industrial systems have all played a part but policies that have emphasised lower food prices may be key.

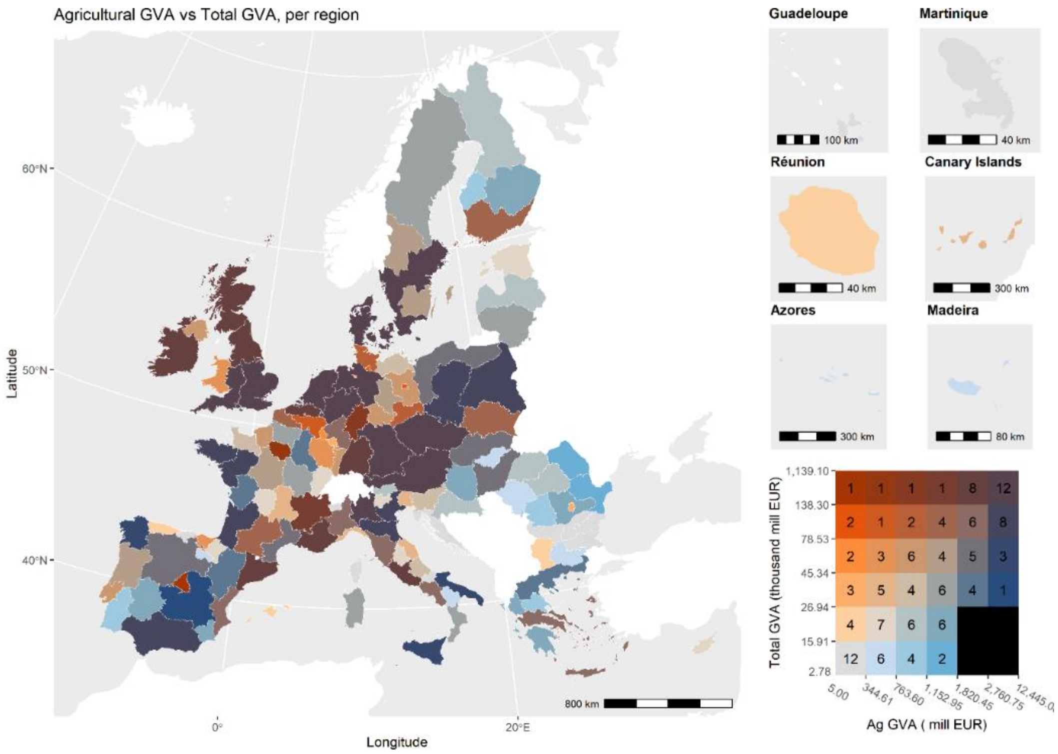

Figure 24: AG vs other GVA by FADN region

3.4.1.7 CAP payments

To conclude the analysis of the funds and flows associated with EU agricultural production systems, this section presents a breakdown of CAP and related payments by Member State and farm type. As will be seen in later sections from Section 3.4.3, many agricultural production systems rely heavily on CAP payment to remain financially viable, and CAP is the largest source of funding for land-based rural development and agri-environment/climate change measures (see Section 1.1.4). The intention here, as with the other flows and funds analyses, is to ground any consideration of the policy narratives and objectives with data on the magnitudes and mechanisms by which support is provided to agricultural production systems. It is worth noting that such an analysis omits other aspects of the CAP such a regulatory control. There is, in theory at least, no imperative that such regulations should necessarily be linked with support payments except in so far as it makes their enforcement easier.

Figure 25 and Figure 26 show the breakdown of the flow of agricultural and rural development spending, per Member State and per farm type. Both figures emphasise the predominance of decoupled (area based) payments which have limited specific requirements (except those associated with CAP Greening). The less favoured area payments (LFA), though part of the second pillar of CAP, are in terms of character very similar to other decoupled payments meaning area-based income support payments are the dominant payment mechanism. Support for specific systems of production have been reduced over time, since they were viewed as market distorting, but they remain and, for some parts of sectors such as breeding livestock, are substantial. Specific environmental payments are a relatively small part of the CAP funding regime and are linked most often to livestock-based system, though are also present supporting measure to limit the negative impacts of cropping systems e.g. through measures to improve water quality.

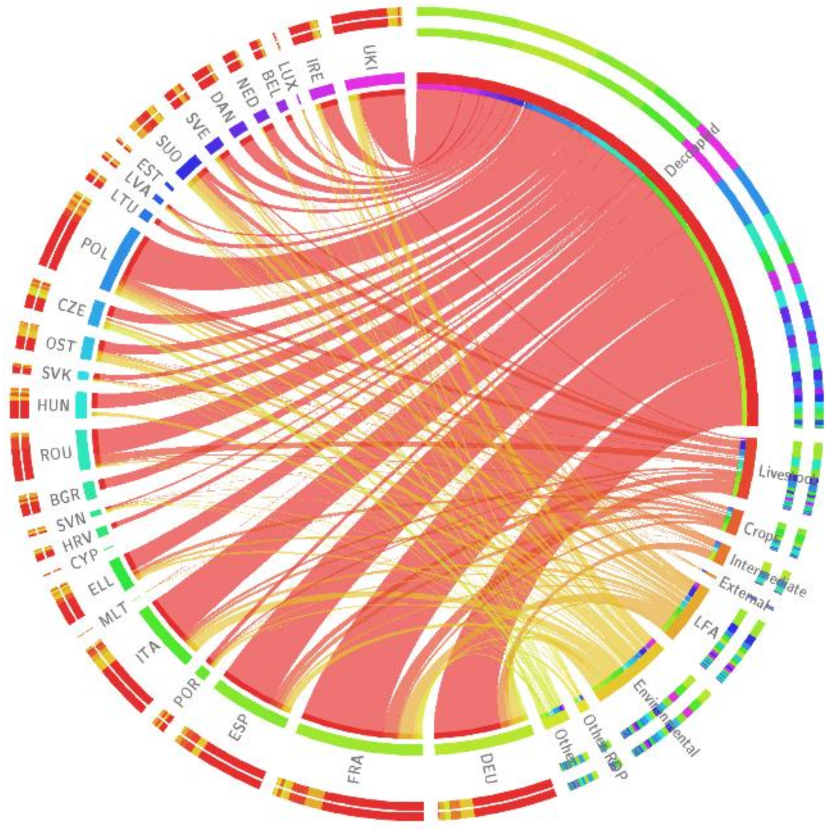

Figure 25: CAP spend per Member State by funding mechanism 2014-17

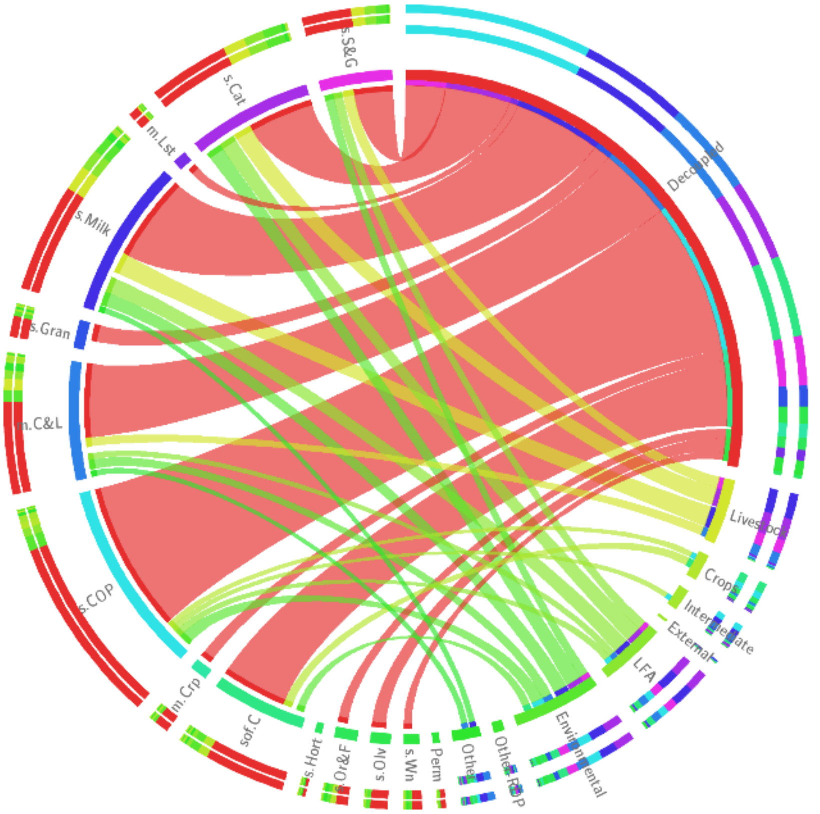

Figure 26: CAP spend per Farm type 2014-17 by funding mechanism

The overall flow of support from CAP to Member States and farm types is shown in Figure 27. This highlights the relative levels of CAP support for systems of agricultural production. It is worth noting that there are production systems such as horticulture and granivores that have not been part of the 'supported sectors'. The mix of production system in terms of support can also be seen in the outer segments for each Member State with very different patterns reflecting both the farm types present but also the choices of Member States or regions on particular systems that need support. The degree of support for farm types that are prominent in the generation of experts (milk and cereals) is significant since their competitiveness in world markets is being underpinned by public funds (see Section 3.4.4).

Regionally, the extent and intensity of CAP funding is presented in Figure 28. This figure highlights the diversity of payment rates (presented here per ha of UAA), both within and between Member States. Regions with higher rates per hectare but more limited overall extent of payments are highlighted in orange, with those having lower rates but larger extents are highlighted in blue. Those regions with comparable rates but differing only in extent due to the size of the region are on the diagonals.

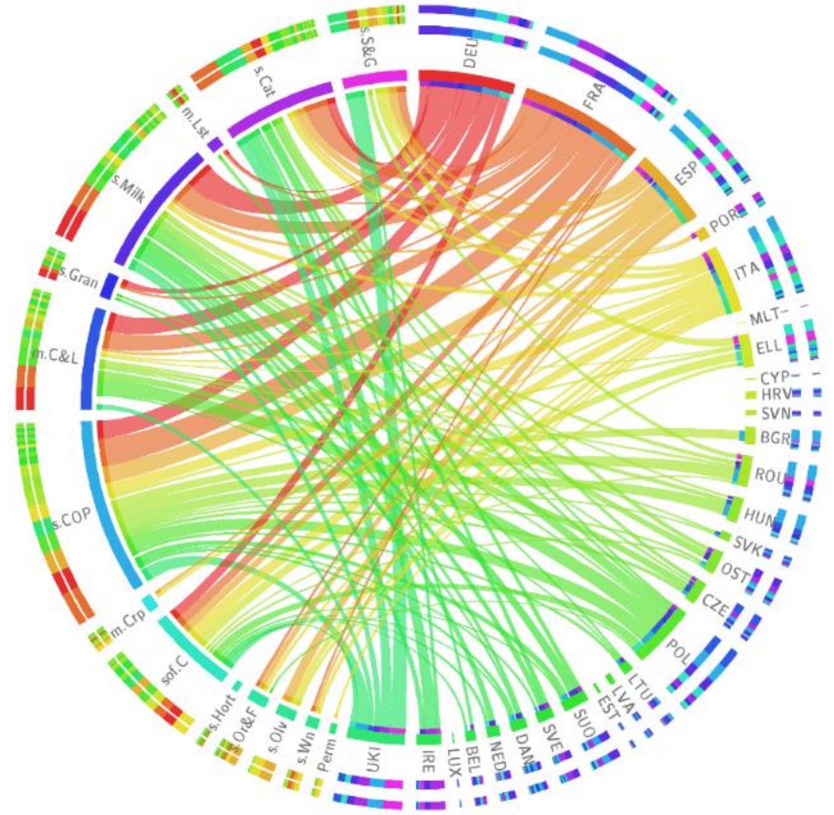

Figure 27: Overall CAP spend 2014-17 by Member State and farm type

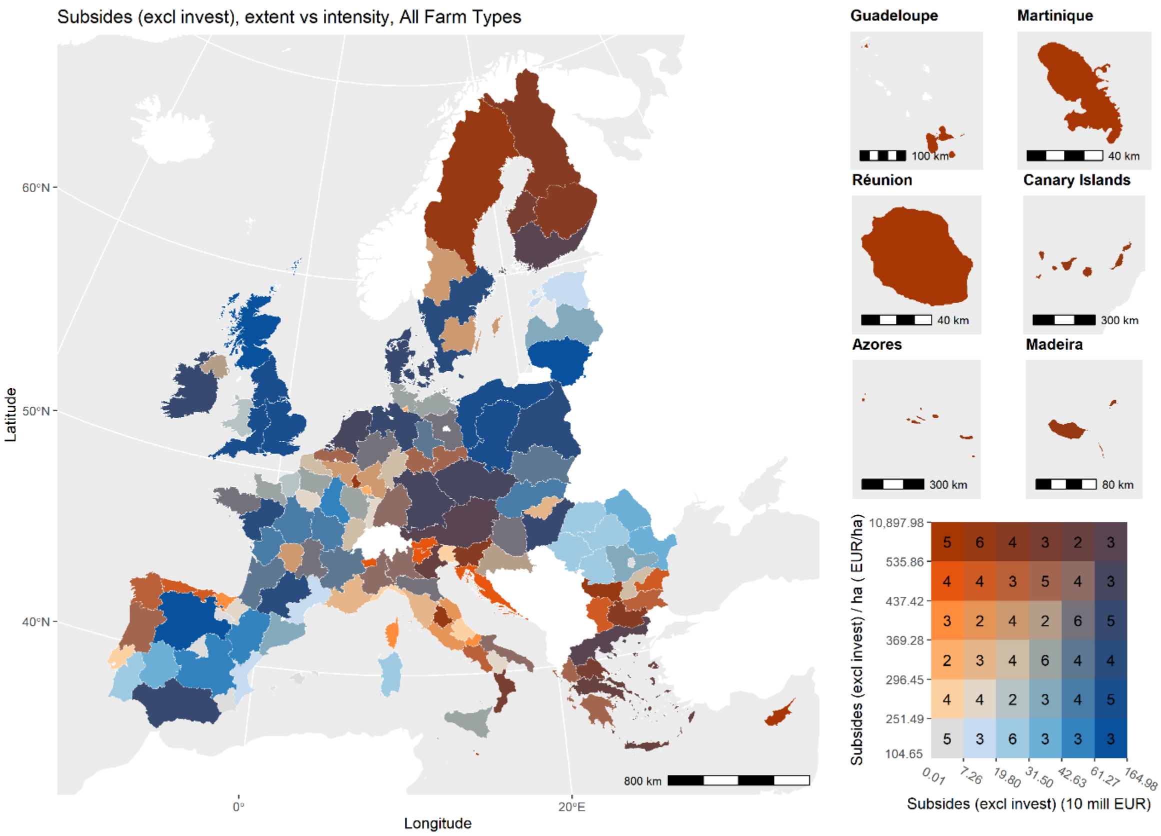

Figure 28: Extent vs. intensity of CAP subsidies

3.4.2 Sustainable agriculture: environmental pressures within the EU

Having characterised the flows and funds of EU agricultural production systems, societal metabolism accounting now considers how pressures may be characterised and how these can be linked with environmental impacts. The objective is to highlight key aspects of the environmental sustainability of such systems, a key component of the objectives of SDG2, especially target 2.4. Again, the intent is to provide a pan-EU perspective with appropriate geographical granularity and production systems details. The environmental sustainability aspects of SDG2 objectives are considered in two parts. First the pressures being exerted (Sections 3.4.2.1 and 3.4.2.2) and second the Impacts (Section 3.4.2.3). These are undertaken in terms of both the extent of inputs to agricultural production systems for Member States and farm types and through mapping extent and intensity for selected variables that can increase pressures on the environment. The next section looks at several pressures that are key to assessing the environmental sustainability of EU agricultural production systems.

3.4.2.1 Pressures

Artificial Fertilisers

A key pressure exerted on the environment arise from the use of artificial fertilisers. Fertilisers are essential if the extent of food production in the EU is to be maintained, and some losses are inevitable. Yet the excessive levels of loss from agricultural production systems to both aquatic and atmospheric sinks are well recognised and have been the subject of numerous policy interventions at EU and Member State-levels (Mekonnen and Hoekstra 2015, 2018). Typically, these have focused on intensity issues, where rates of fertiliser use exceed the local ability of ecosystems to buffer and mitigate the negative impacts. A focus mainly on intensity issues though misses a key aspect of artificial fertiliser sustainability: the overall extent of use. Use of fertilisers at rates that avoid local impacts may still be having negative impacts, for example on the diversity of soil biota, with implications for soil health and resilience, or via atmospheric losses at low rates but so extensively such that their contributions to GHG concentrations is significant (European Environment Agency 2019)[10]. Nitrogen (N)-based fertilisers also have a significant embodied energy cost, and phosphorous (P) has limitations on availability such that it may be better in policy terms to consider it as stock rather than a renewable fund. The latter also needs to be considered as a future food security issue.

The extent of N and P fertiliser usage by Member States and farm types is presented as chord diagrams in Figure 29 and Figure 30. In terms of farm types, the largest direct user is specialist COP, but it is worth remembering that since a significant part of that production is used for animal feed, then livestock production is a more significant indirect user of N and P fertilisers. Other heavy users of fertilisers are field crops and dairy systems where the desire for greater control over the quality feedstuffs means greater use of home-grown feeds. The analysis highlights that in terms of extents, Poland is the largest user of fertilisers, with a wide variety of production systems being supported. Other notable users are the UK and Ireland where N use is higher with the greater reliance on grass-based systems, contrasting with Italy and Romania where P is greater from field crops and cereals. Note that for both fertilisers the extent of their use locally within the EU is reduced by imports of agricultural commodities, and processed foodstuffs and is increased by exports of the same (see Section 3.4.4).

[10] Agriculture is a significant emitter of GHGs (sixth largest in 2019) and with limited progress in their reduction -19 % reduction between 1990 and 2019. https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-3

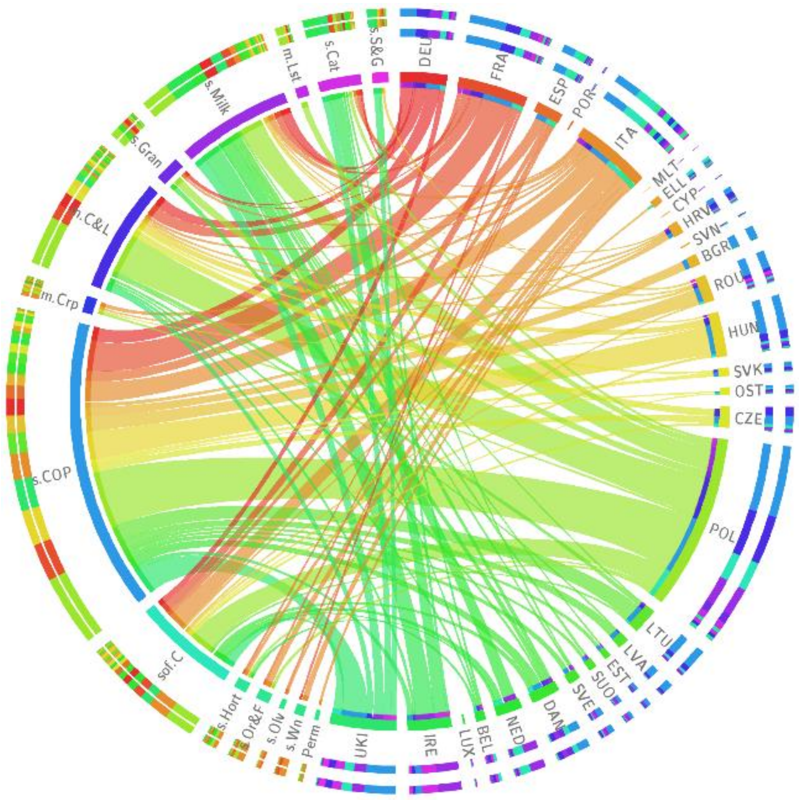

Figure 29:N use tonnes 2014-17 Member State and farm type

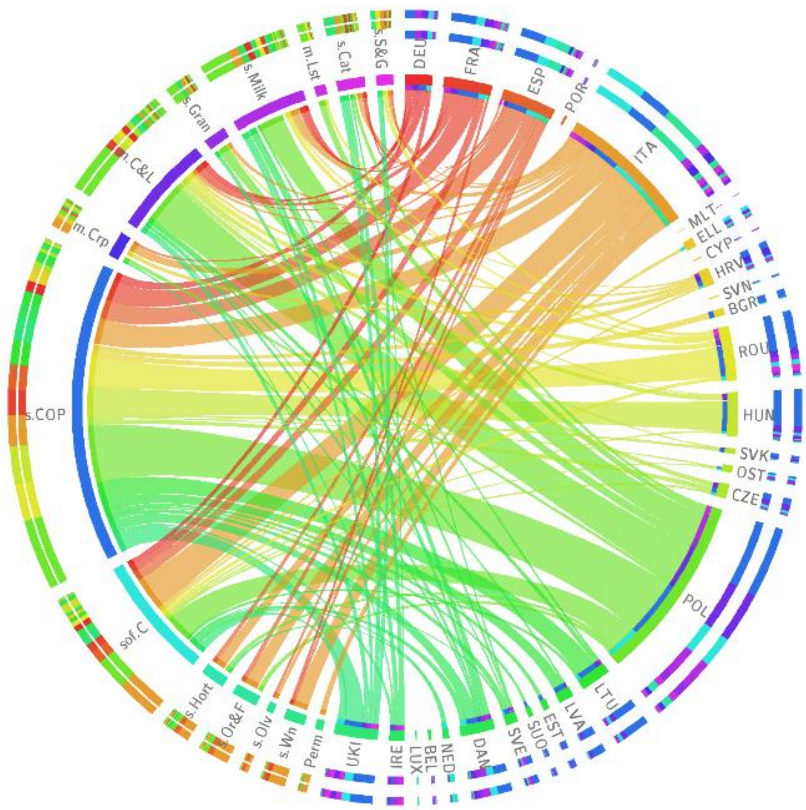

Figure 30: P use tonnes 2014-17 Member State and farm type

Crop Protection Products

Another key aspect of the pressure exerted on the environment by agricultural production systems is the use of crop protection products, including pesticides and herbicides. Here, pressures are on biodiversity loss but potentially also raise concerns for human health. Loss of predator species may also mean a need for ever-greater use of crop protection and the loss of pollinators can pose direct risks to food production feasibility and viability. Figure 31 highlights the extent of usage of crop protection products by Member State and farm types. The analysis here is significantly limited by its basis entirely on crop protection expenditure data in Euros. It would have been preferable with physical quantities (tonnes) and types such that estimates of active ingredient and potential ecotoxicity could be used. Given the diversity of production in use, this is not an insignificant data collection task but given the importance of the pressure, this may need to be prioritised.

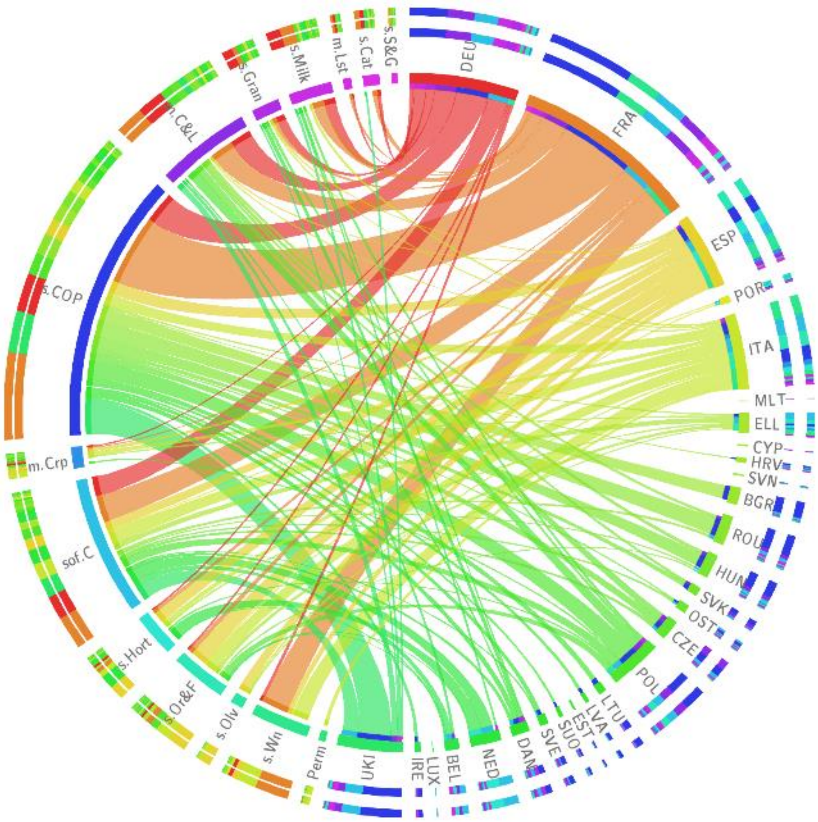

Figure 31: Crop Protection € 2014-17 Member State and Farm Type

The figure highlights that, in contrast with fertilisers, the heavy use of crop protection products is more prevalent in western Europe, particularly for countries with significant exposure to fruit and vegetable production (France, Spain and Italy). Again, it is worth noting that specialist COP production, because of its extent, is the single biggest user of crop protection products (with France being the largest single user). This highlights that ,in terms of pressures, it is necessary to consider both extents and intensities of use. Reducing the overall burden on the environment from the use of crop protection products would be highly desirable. Initiatives in integrated pest management[11] using biological controls are available but are not yet in widespread use for a variety of reasons (Birch, Begg, and Squire 2011).

[11] For an overview of integrated pest management see https://ipm.hutton.ac.uk/

Water

Water use in terms of quantity is a significant sustainability issue in the EU, both for the environment and for risks to food production. Agricultural production systems have the potential to divert significant volumes of water from their natural flow pattern, and while water is an essential part of agricultural systems, there is an expectation in the EU that agriculture will be conducted in a way that is compatible with the WFD objective of maintaining or returning EU water bodies to their reference conditions (pre-Industrial status) unless this is economically unfeasible. This means the need to maintain minimum "ecological flows" that allow rivers and other water bodies to deliver their ecosystems functions. Systems of agricultural production that rely on irrigation can be highly productive, and can be sustainable when water abstractions remain below maximum sustainable levels (Hoekstra and Wiedmann 2014; Hogeboom et al. 2020), which depend on natural recharge and flow rates and environmental water requirements. Yet when such systems exceed these maximum sustainable levels, they tap into water flows that are needed to preserve aquatic ecosystems and deplete water stocks in the long term. The latter will also likely be exacerbated by climate change with increased evapotranspiration and more uncertain patterns of rainfall.

The metabolic patterns of water use for the EU are presented in Figure 32 to Figure 35 The figures show the relative extent of usage per Member State and the mix of uses in terms of farm types.

Water usage by Member States and farm types – 2014-17

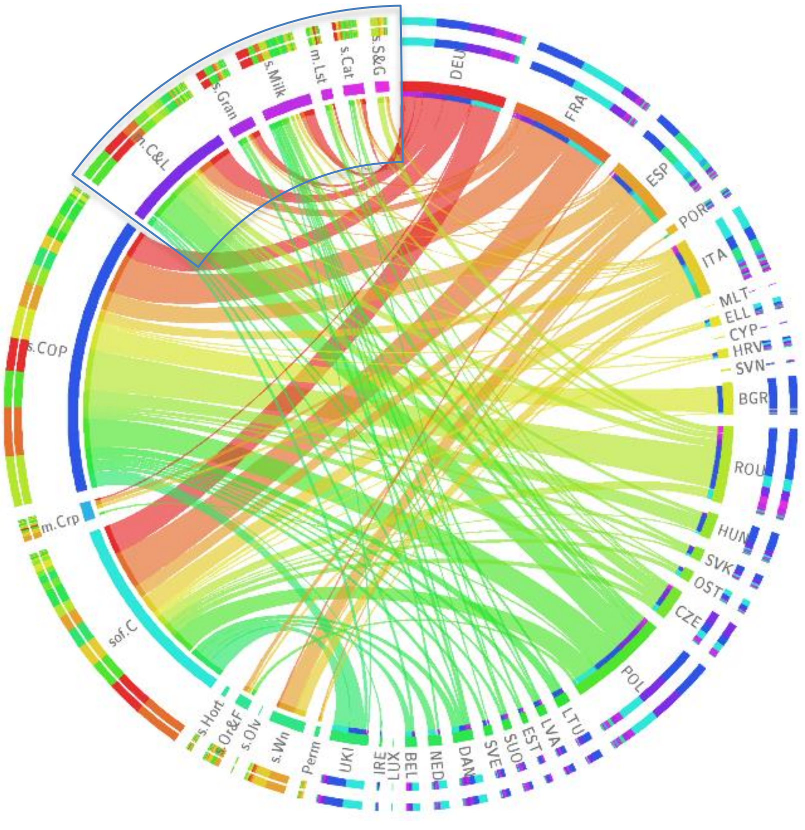

Figure 32: Water-green, local, crops

Water usage by Member States and farm types – 2014-17

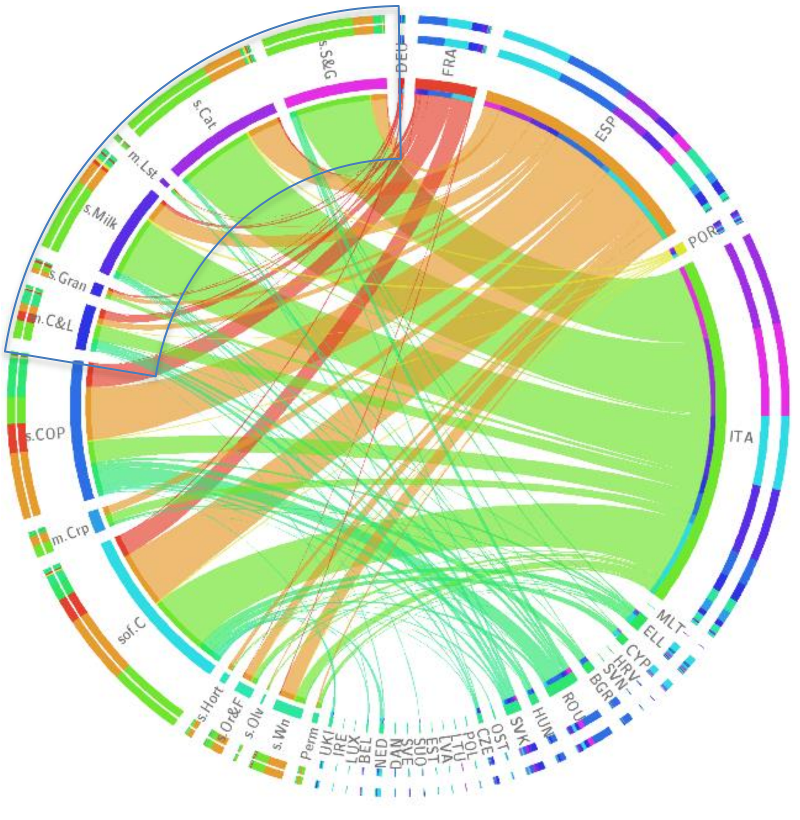

Figure 33: Water-blue, local, crops

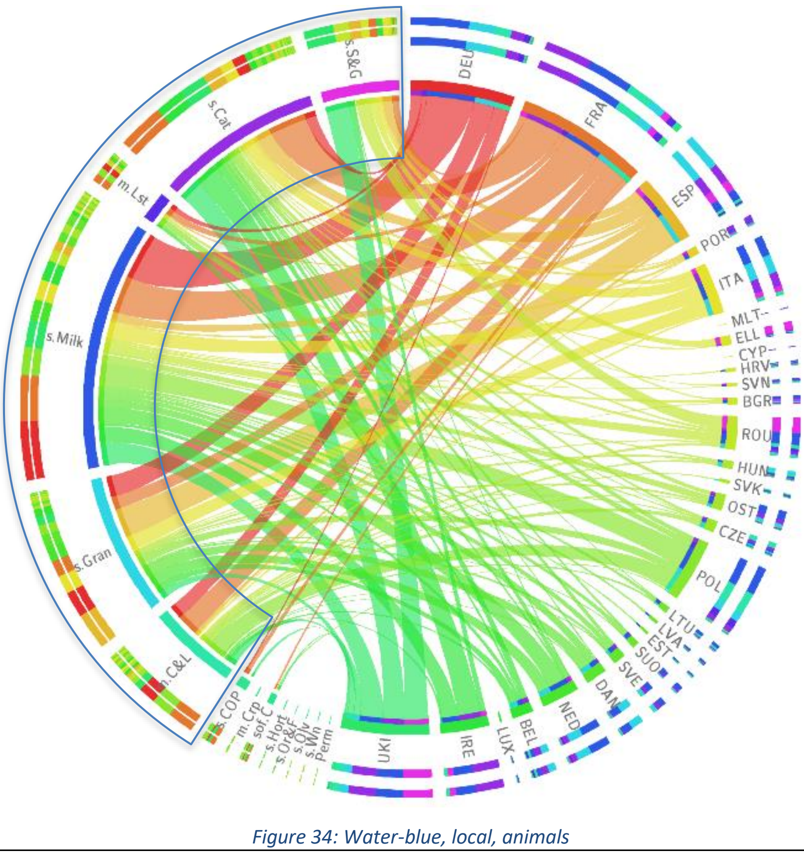

Figure 34: Water-blue, local, animals

Water usage by Member States and farm types – 2014-17

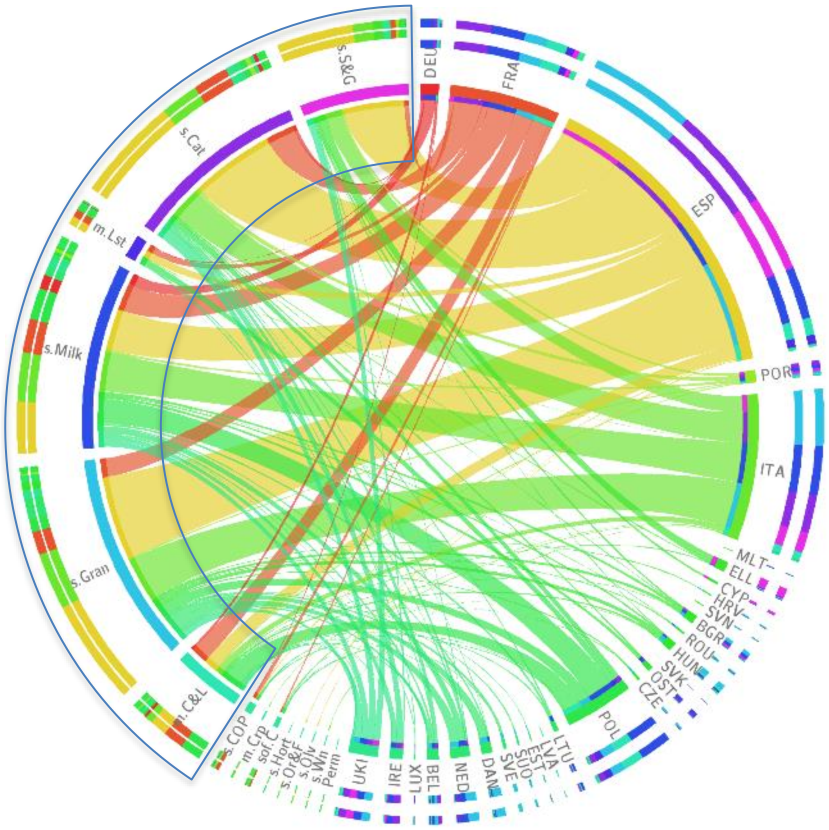

Figure 35: Water -blue and -green, imported, feed

The figures distinguish between: Figure 32 green water: the direct evapotranspiration of precipitation from the crop field, which is 69% of the water used by agricultural production systems; Figure 33, blue water: evapotranspiration of irrigation water diverted from surface and groundwater bodies, which overall is 16% of the water used but is much higher in particular regions; Figure 34, blue water used locally for animals (drinking and servicing), which is only ~1% of all water used; and Figure 35 green and blue water used to produce animal feed imported from beyond the EU making up 18% of all water use. The balance between crop and livestock-based uses is highlighted by the segments in the figures.

The water use figures emphasise the importance of the effects that agricultural production systems have on hydrological processes, partly due more intensive uses, such as blue water for irrigation (for example in Spain and Italy), but potentially also through the use of green water since this use is so extensive. The draw on green and blue water beyond the boundaries of the EU is also significant since it allows countries that would otherwise struggle to support the numbers of livestock present to sustain these numbers, potentially also generating issues for waste management. Overall patterns of water use suggest that the intensity of production is likely above that which is sustainable, particularly when faced with changes due to climate change or any substantial limitations in the availability of imported animal feed.

3.4.2.2 Pressure mapping

In addition to the chord figures it is possible to generate relationship maps that provide more detailed insight into regional patterns of pressures, albeit limited to FADN regions[12]. For each of the metrics, the maps highlight those cases where there are instances where intensities are high but extents are low (lighter oranges)[13], yet also cases where even relatively modest rates result in large overall extents of usage (lighter blues). The maps emphasise the need for care in interpreting some Member State-level data since there can be very substantial variation within larger Member States (e.g. France). This emphasises the challenge of designing any common pan-EU policy instruments that are effective in delivering specific sustainability objectives.

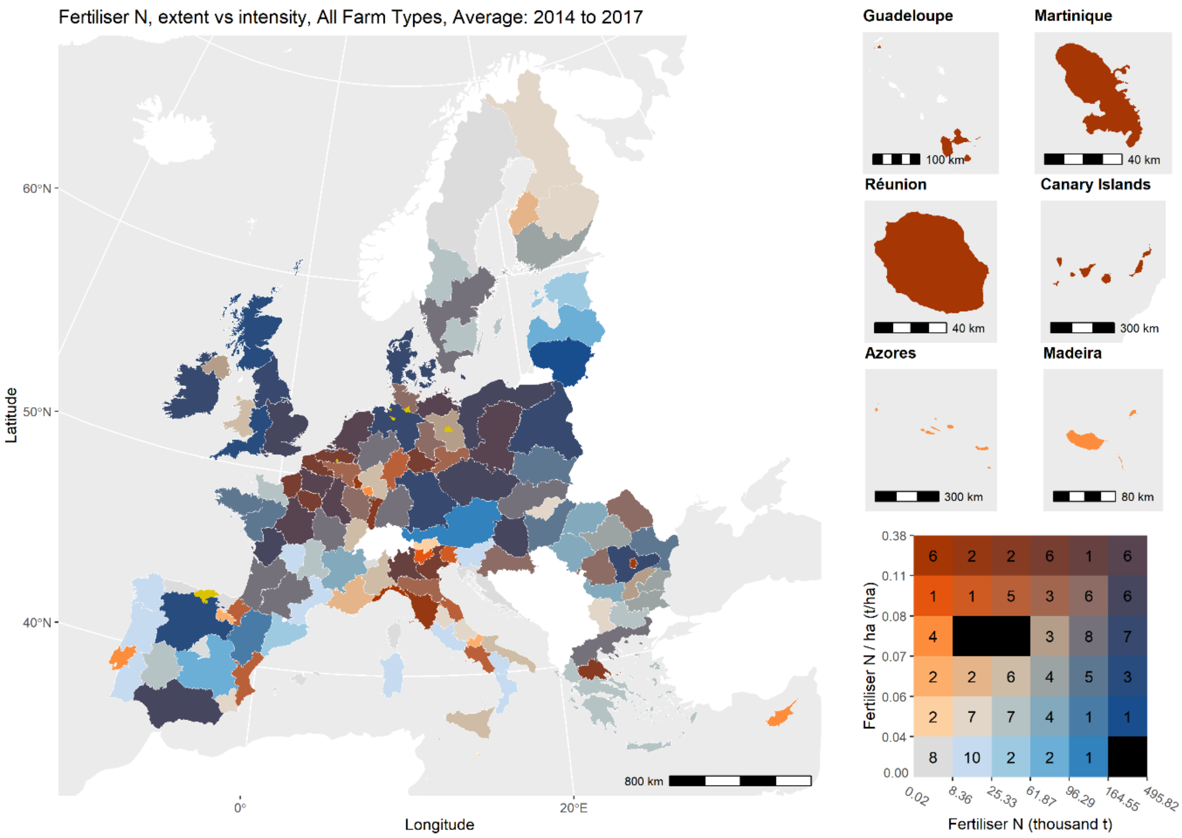

Figure 36: Extent versus intensity map for Nitrogen fertiliser use

[12] It is also possible to generate maps series looking across farmtypes to highlight combinations of region and farm type exerting greater pressures.

[13] This is though partly a feature of the variable size of FADN units.

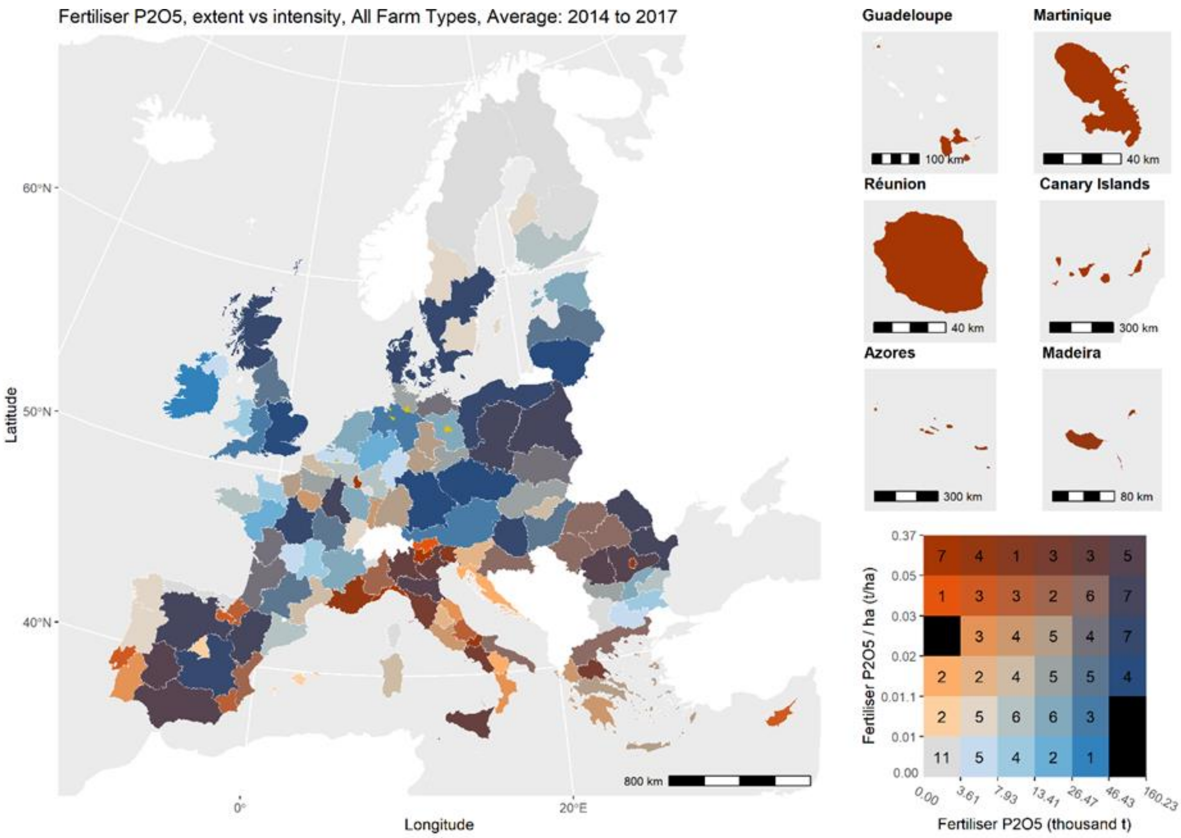

Figure 37: Extent versus intensity map for Phosphorus fertiliser use

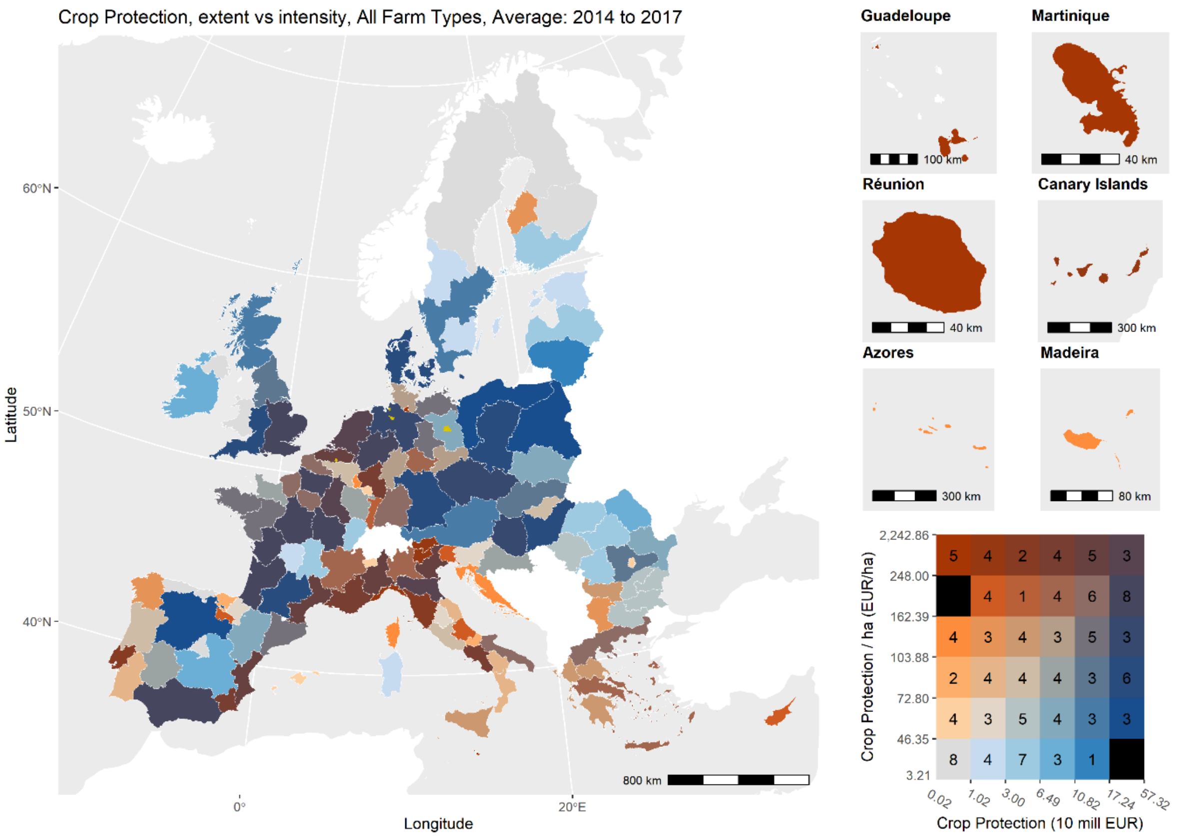

Figure 38: Extent versus intensity map for crop protection use

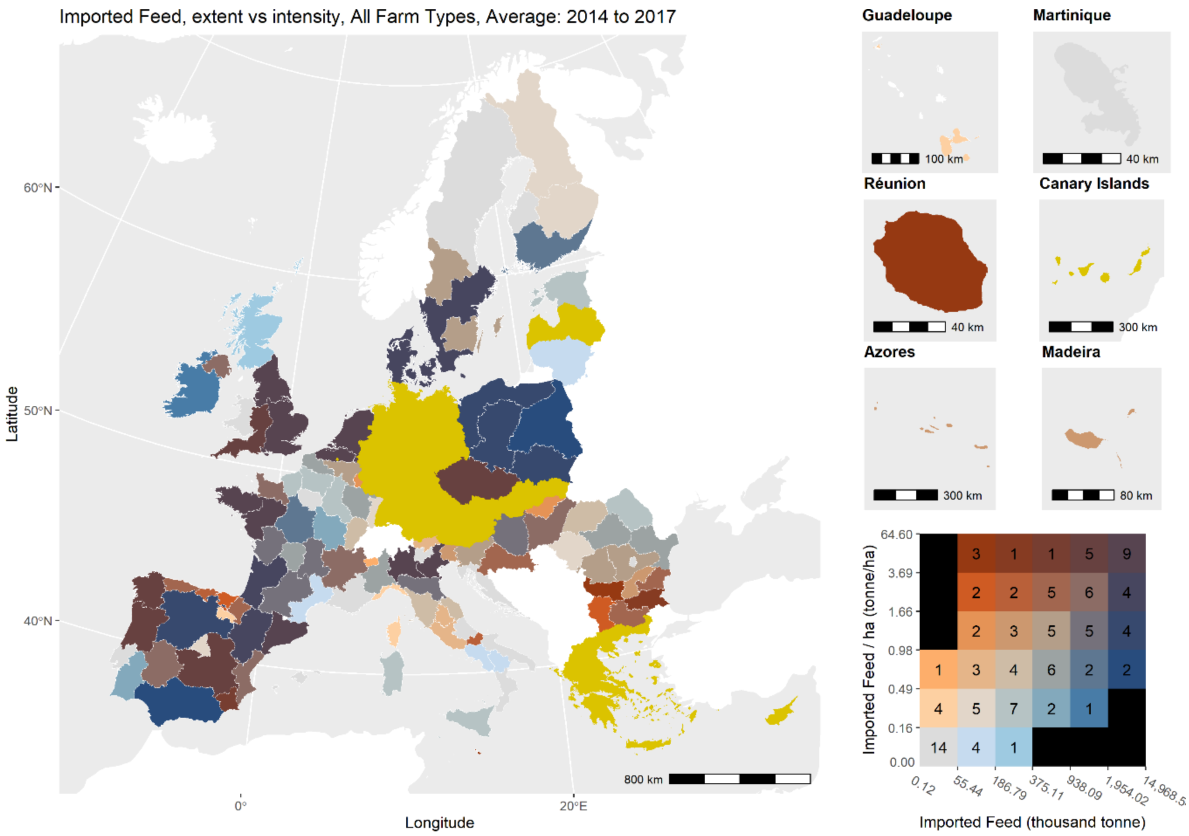

Figure 39 Extent versus intensity map for Feed - Imported Forage Crops (Non-Domestic)

In addition to the relationships maps for the variables used in the chord diagrams in Section 3.4.2.1, it was also possible to generate a further relationship map linking numbers of livestock units and the associated land area (both grass and forage crops). Combining these generates a form of stocking rate (that accounts for both grazing land and forage crops, though not the use of other feedstuffs). The relationship mapping format again provides a more nuanced view of the metabolic patterns within Member States than would be given by simple stocking rate map. The map highlights those regions where numbers of stock and stocking rates would be expected to be higher (UK, Ireland, Netherlands and north Germany), but also highlights regions (light blue) in southern Europe where there are livestock systems with more limited numbers but based on much smaller land areas (likely specialist granivore system using imported feeds). Again, stocking rates for specific livestock farm types can also be generated but here the focus is on identifying those regions where, on aggregate, livestock systems are likely to be putting pressure on the local environment.

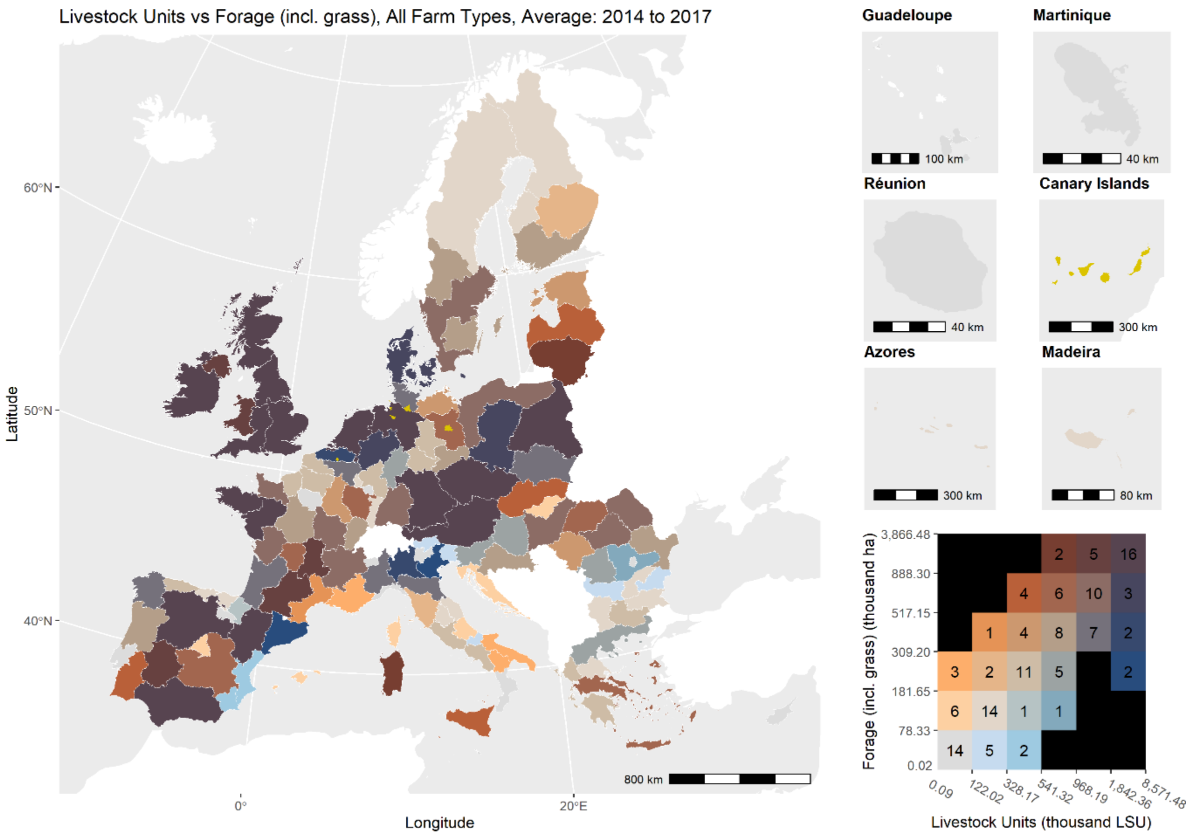

Figure 40: livestock stocking rates

3.4.2.3 Impacts

Having looked at the pressures on the environment being exerted by EU agricultural production systems, this section aims to assess the degree to which the negative outcomes of these pressures should be taken seriously. To do this the data from the societal metabolism accounting characterising FADN regions was combined with data on the state of the environment. The intent was to take a very high-level view of the state of terrestrial and freshwater ecosystems and consider how pressures from agricultural production systems may be causing impacts on such systems. Figures illustrating relationships were generated and discussed with stakeholders and these can be seen in Appendix III: Slides presented when closing the QST Loop.

3.4.2.4 Pollinators

Pollinators are a key biodiversity indicator for agricultural production systems as they span both provisioning and other biodiversity-related ecosystem services. Data on such indicators is notably sparse at pan-EU level and for this analysis, reliance was placed on a modelling-based study that estimates the potential for pollinators based on a range of spatial data (Maes (2010). The grid-based pollinator potential data was summarised for FADN regions and is presented in Figure 41 as an extent (sum of potential pollinators values) versus intensity (the mean potential for the region) to allow comparison with the pressures and other maps within the deliverable.

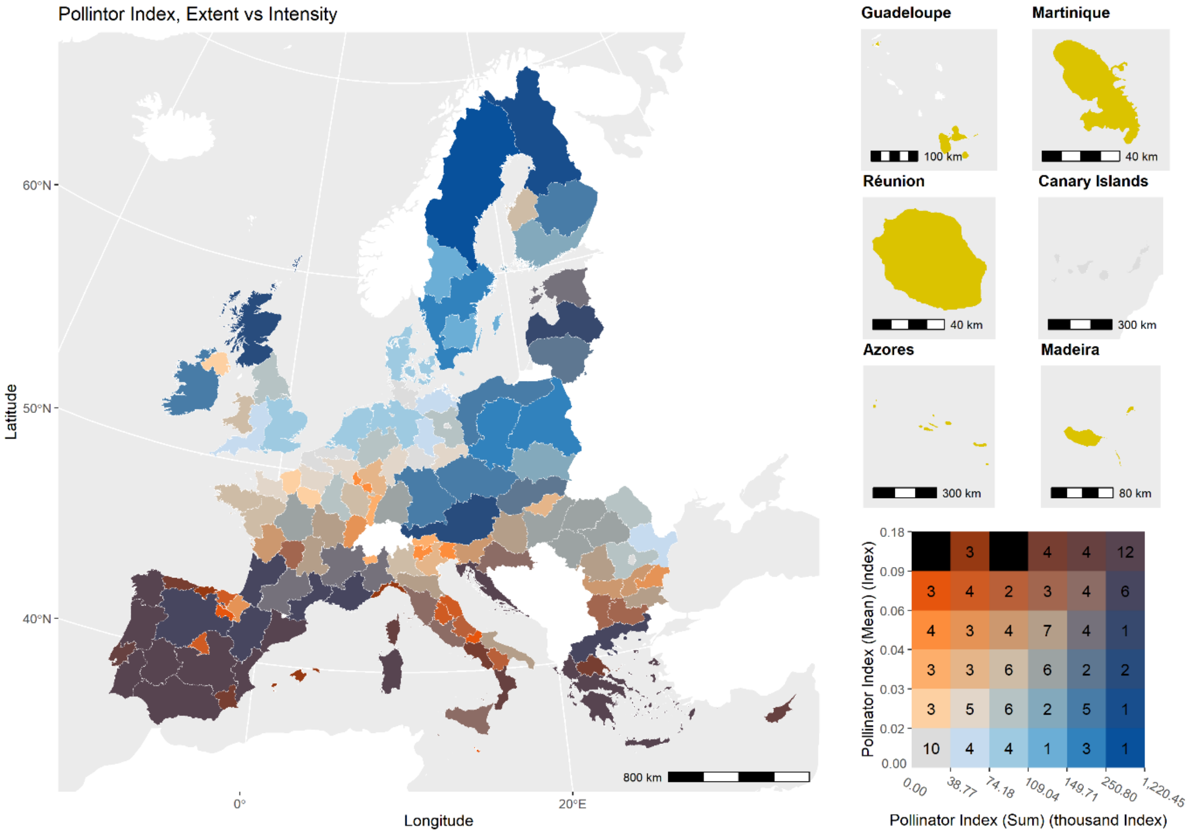

Figure 41: Extent and intensity of pollinators index

The pollinator index has a maximum value of 1.0 and this maximum value is present in the higher resolution data from which the averages per FADN regions are derived. The highest mean value for the FADN regions is though only 0.18. This means that while there are regions doing better than others (broadly south versus north Europe) for the potential for pollinators, the overall picture is one where the most extensive land use systems are, on average, hostile environments for key insect species. That within particular FADN regions there are areas less hostile to pollinators is clear from the higher resolution mapping, but it remains a challenge to link data on the management practices of agricultural production systems to these outcomes, since the since FADN data becomes progressively less representative and reliable as smaller spatial subsets are considered (even when restrictions on the use of FADN data at such higher resolutions can be overcome).

3.4.2.5 Soil erosion

For EU agricultural production systems, soils are a key fund which would, if managed sustainably, continue to deliver provisioning, regulating, and supporting ecosystems services (e.g. carbon sequestration and soil biodiversity). The fund of soil is however not only altered in terms of quality and function through process of agricultural production but may also be subject to loss through erosion by water and wind, with rates of loss exacerbated by unsustainable land management practices. Soils are a renewable resource, but only weakly, with rates of soil formation estimated as varying from 1.0 to 3.0 tonnes per ha per annum. These soil forming rates give an external referent against which to judge the sustainability of agricultural production systems. Figure 42 presents and extent versus intensity relationship map for soil erosion based on data from the EU Joint Research Centre (2015). The highest rate of loss categories tends to be associated with FADN regions containing mountains where slopes and thus erosion rates are highest. It is likely that rates for these areas would be substantially lower if the land with agriculture production systems present were included.

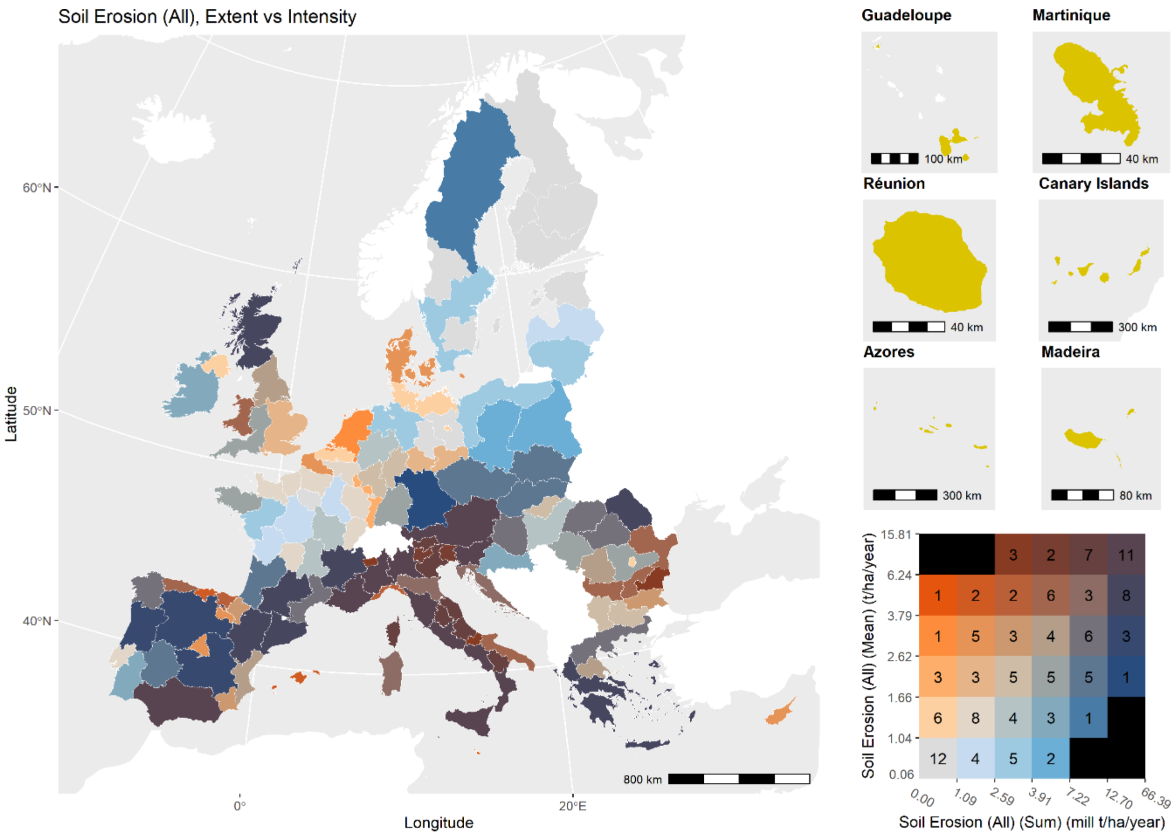

Figure 42: Extent and intensity of soil erosion by water and wind

Yet even where such systems are present, in over 90% of the FADN region land there are rates of erosion above 3.0 t/ha/year, which is unlikely to be sustainable. Only the lowest class in the intensity classification falls below 1.0 where it is likely that erosion is not a serious issue. This means that the great majority of the land within EU agricultural production systems is experiencing a rate of soil loss that is depleting the fund of soils. Such losses are potentially an existential threat to food supplies and other ecosystem services.

3.4.2.6 Water quality

For water quality, an external referent is provided by ecological status as defined by WFD reporting, with the threshold set as being at good or better status compared with pre-industrial conditions. The extent variable used was the length of linear features (rivers etc.) and the intensity variable was the proportion achieving good ecological status. Despite the EU being at the end of the second WFD reporting period (i.e. 14 years into the process of improvement) there are very few regions in which more than 50% of the rivers have good ecological status and a substantial number where the percentages are very low (<20%) . Not all the lower ecological status values are due to the direct effect of agriculture with point source pollution (e.g. industrial or wastewater treatment) and morphological modifications also contributing. Even for diffuse pollution, agriculture is not the sole source, with rural domestic sewage systems and recreational uses (such as golf courses) also seen as contributing. It can also be the case that for heavily modified water bodies, the best status that can be achieved is limited to good potential. This would affect areas such as the Netherlands and others with extensive systems of artificial drainage and inland waterway-based transportation. Even with these caveats it is difficult not to conclude that there are significant challenges in achieving the sustainable water management objectives and that in areas with more intensive agriculture, achieving good ecological status appears to be challenging.

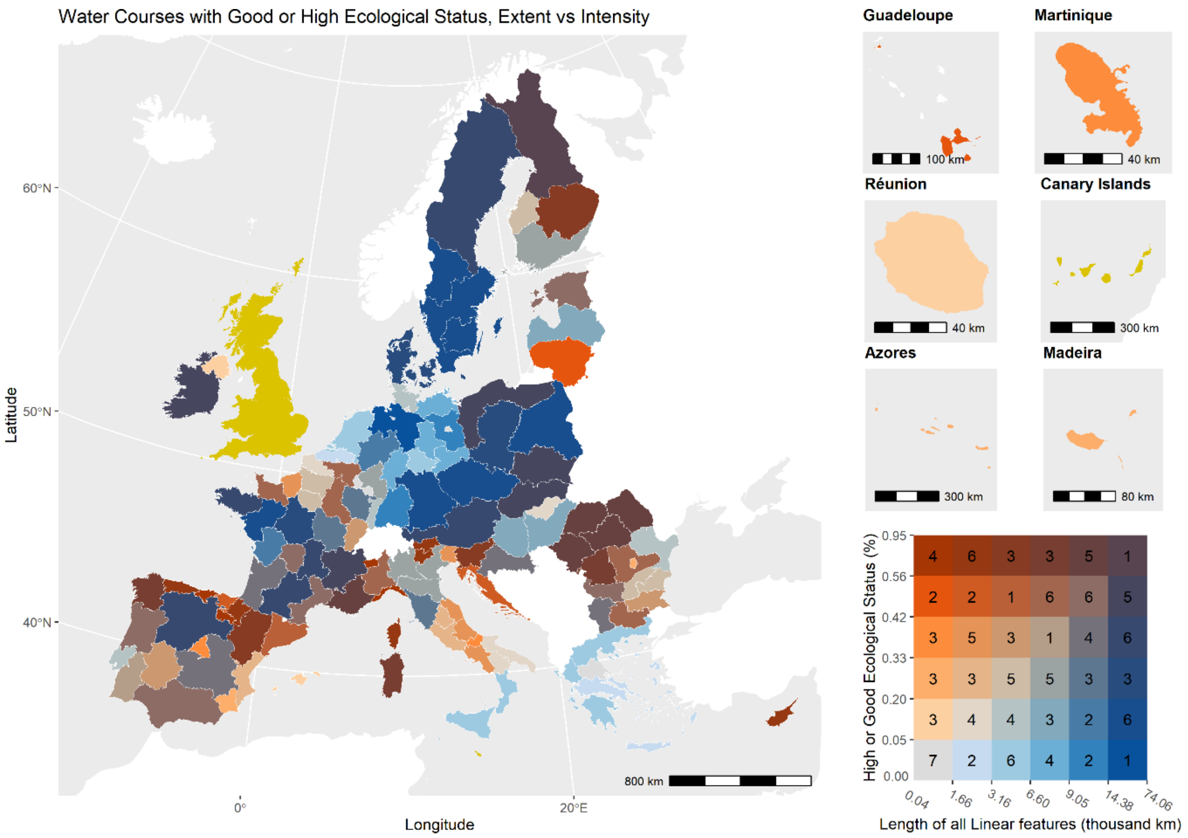

Figure 43: Extent and intensity of good ecological status for rivers

3.4.2.7 Water quantity

For water quantity there is again a benefit in contextualising the societal metabolic accounting of water use in agricultural production systems by some kind of external referent to say how significant the use of water is. This has been done using the analysis by Schyns et al. (2019), which delivered insights on the extents of usage (using similar methods to those in this analysis) but also derived the percentage of the sustainably available green water being used[14]. Water use in agricultural systems is mostly green water (Section 3.4.2.1). Yet rainfall is limited in time and space, and not all rainwater can be allocated to biomass production for human end-use, because natural vegetation depends on these water flows as well. Hence, there are maximum sustainable levels to green water use (Schyns et al. 2019). Figure 44 presents an extent vs intensity relationship map for green water use, with volume used on x-axis and percentage of green water used on y-axis. What is apparent from the map is the degree to which regions are in nearly all cases exploiting green water right up the limits (the lower limit for the second most intensive class is 73%) and are in the top two classes exceeding 100%, in some cases significantly. This means that further increase of green water flows (to produce more food) is hardly possible without adversely affecting terrestrial ecosystems. Southern Europe is known for its relatively low water availability leading to competition between water uses over limited surface- and groundwater resources: water scarcity. Yet, Figure 43 shows that in northern Europe, competition over limited evapotranspiration flows – green water scarcity – is fierce. These regions are also core regions for EU agricultural production systems, so there are implications for long term food supplies as well as environmental sustainability.

[14] This imposes limitations on the share of total green water that can be used so that ecological existing objectives such as Aichi targets can be met.

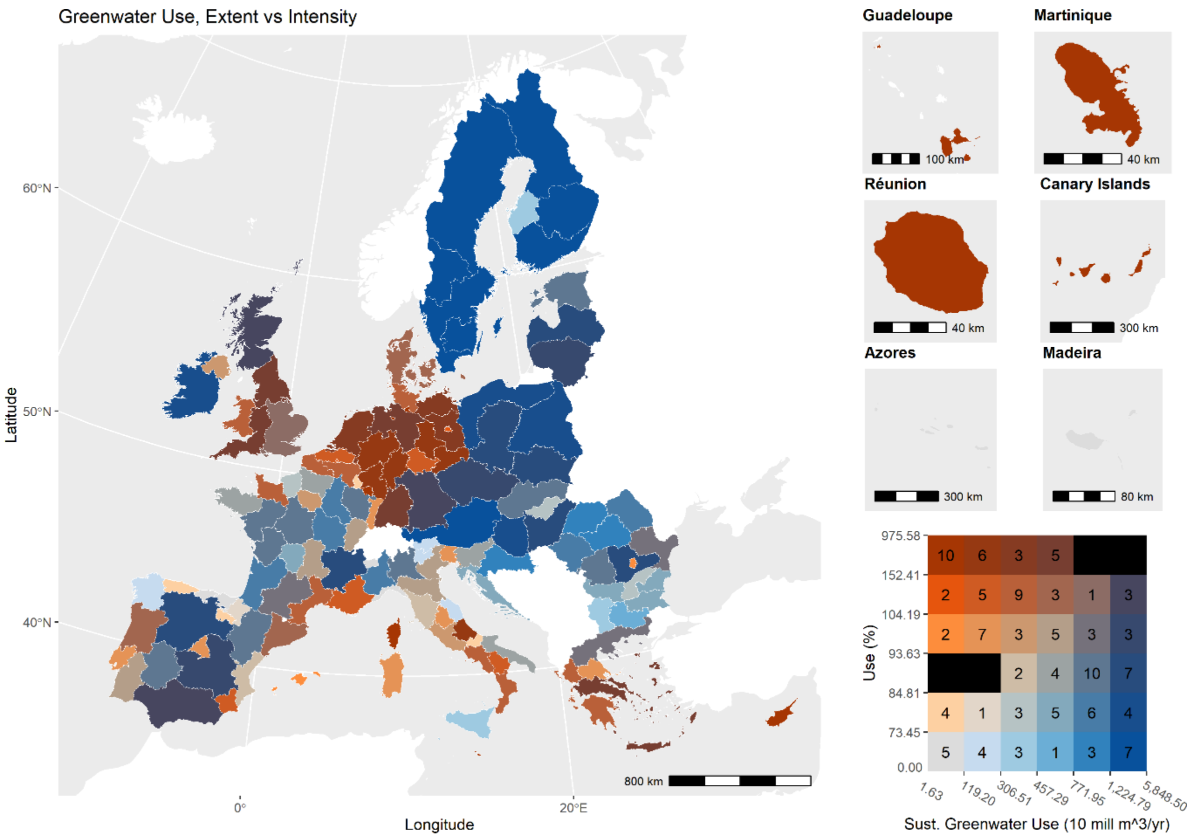

Figure 44: Sustainable green water use

3.4.2.8 Limitations on the analysis

In completing this section looking at environmental pressures and impacts, it is worth noting where limitations remain, where there are opportunities to further exploit existing data and where there would be value in revising existing data collection processes to provide key metrics.

Exploration of relationships within the components of the FADN and related datasets has been limited, and the relationships seen have been difficult to interpret. While this would be expected for any complex system with the diversity of EU agricultural production systems, the data integration achieved within the analysis means that further insights may be gleaned especially with more sophisticated statistical analysis methods than employed to date. The caveats on how feasible attribution of specific causation is within any analysis of such systems remains, due to the need to consider processes that are affected by different factors that can only be observed across different scales and dimensions of analysis. The co-existence of different directions of causality observable only at different scales entails the unavoidable existence of impredicative relations (i.e. egg-chicken paradoxes) and double contingency (i.e. two interacting agents anticipating the possible reaction of each other) making it impossible to characterise the behaviour of social-ecological systems in a deterministic way (Giampietro 2019).

There are opportunities to take more specific commodity or production system perspectives, such as cereals or cattle. Such analysis would provide more specific insights relevant to particular policies or policy instruments (e.g. individual coupled payment schemes). Yet interpreting such analysis depends on the context provided by the system-wide analysis undertaken here. The overall caution noted earlier about making the analysis easier by making it smaller remains (knowing more about less). The analysis has made some progress in exploring the potential for cross-scale data integration linking biophysical and production systems data. The challenge remains though to find better ways of linking data on biophysical phenomena that are more frequently monitored or modelled at granularities compatible with field or farms (land cover) with agricultural production systems (land use or management) data that is at best available at regional or landscape scale.

The policy relevance of the analysis, for DG's beyond Agri, would be considerably enhanced were key aspects of the FADN data available as physical quantities. Already noted were the crop protection products and machinery in terms of power capacity, utilisation and off-farm sources. While for energy and circular economy policies the focus should be on post farm-gate systems where an estimated 80% of energy is used and most avoidable waste is generated. There are also small changes to FADN that would make energy use within agricultural production systems much more transparent. The data within FADN are expressed in terms of Euros and while there is some detail in terms of motor fuels and heat, for an energy analysis to be effective, the nature of the energy carriers used needs to be explicit and represented in physical terms (Giampietro et al. 2014).

3.4.3 Sustainable agriculture: socio-economic pressures within the EU

Societal metabolism accounting is also concerned with providing insights into the viability of system. That is, those aspects of the system directly under human control (the technosphere). While in the previous section the focus was on the environment and the feasibility of agricultural production systems operating in a sustainable way, this section focuses on the viability of these systems in financial terms. In particular, the section addresses how the financial viability of private enterprises is underpinned by public finance (CAP payments).

3.4.3.1 Incomes in the agricultural production systems

Figure 45 uses the chord diagram format to present the Farm Net Income (FNI) for Member States and farm types[15]. FNI can be understood as the financial value generated by agricultural production systems, and includes the costs of wages and other fixed costs such as buildings and machinery, as well as variable costs that can be attributed to specific production activities. FNI is in effect the value to the sector and provides and indicator of competitiveness, potential for reinvestment or potential for change in management. It also provides an indication of the degree to which the sector could reduce production or increases costs were this needed to achieve higher environmental or social sustainability standards. Agricultural production systems operating consistently below a FNI of zero are possible but rely on other sources of income to remain in existence. Such sources may include off-farm work, on-farm diversification (energy, food processing, retail, tourism) or income from other investments.

Figure 45 highlights that in terms of FNI, some sectors generate considerably greater net income than their extents would imply. These include specialist wine, olive, orchards and fruit and horticulture. Specialist cereal production, despite the large areas, flows of inputs and substantial subsidies, has a relatively modest aggregate FNI. For livestock systems, specialist milk has the largest FNI despite the volatility of milk prices and market access over the 2014-17 period. Looking at FNI value over time, it was apparent that aggregate values hide quite wide fluctuations such that in particular years, otherwise consistently profitably farm types in a particular Member State can see negative FNI values. It is also apparent that positive FNI values were in a significant number of cases dependent on the presence of CAP subsidy payments.

[15] It is worth noting that financial arrangements for particular Member States can make comparisons using FNI challenging. In particular FNI tends to underestimate the income for farms in France where a form or rent is paid to another financial entity even when land is owned.

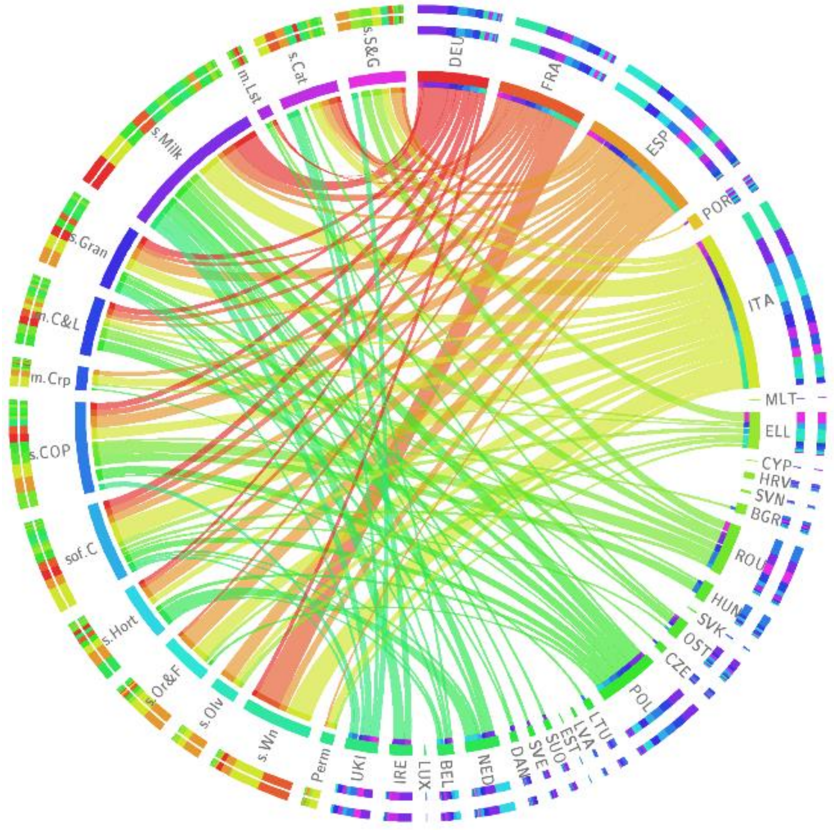

Figure 45: FNI 2014-17 by Member State and farm type

Figure 46 elaborates the degree to which, for Member States and farm types, financial viability depends on CAP subsidy. The figure presents for 2014-17 the sum of NFI minus all CAP payments for all cases where elimination of subsidies would result in a negative value for NFI (i.e. CAP payments are greater than FNI). This is effective in highlighting where farming systems could operate without subsidy (e.g. Spain and Romania) and where subsidies are a significant part of financial viability (e.g. Germany, France, UK and Scandinavia). Sectorally the dependence on subsidies for specialist cattle is striking (compared with specialist sheep and goats) as is the dependence of mixed crop and livestock businesses. The marginal financial viability of specialist cereal production is particularly noteworthy, since this production system has a major exposure to exports, so in effect public funding is used to underpin the provision of food at prices that mean the sector has only marginal financial viability.

Figure 47 provides a further perspective on agricultural production systems' viability, presenting a relationship map between FNI and subsidies per FADN region. The figure highlights where subsidies are high, yet net farm incomes are low (the lighter orange regions) and where despite lower rates of subsidy, higher regional aggregate net-farm incomes are being achieved (lighter blues). While such regions are not uncommon, at this aggregate level there is quite a strong linkage between the FNI and subsidy payments (regions along the central diagonal of the legend).

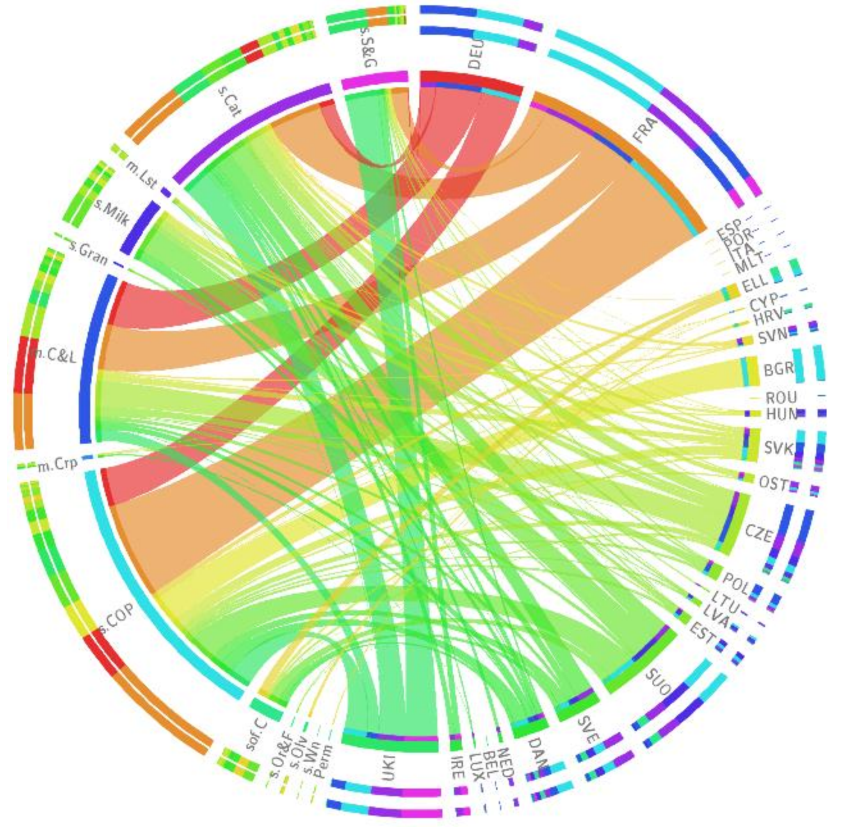

Figure 46: FNI minus CAP 2014-17 negatives only by Member State and farm types

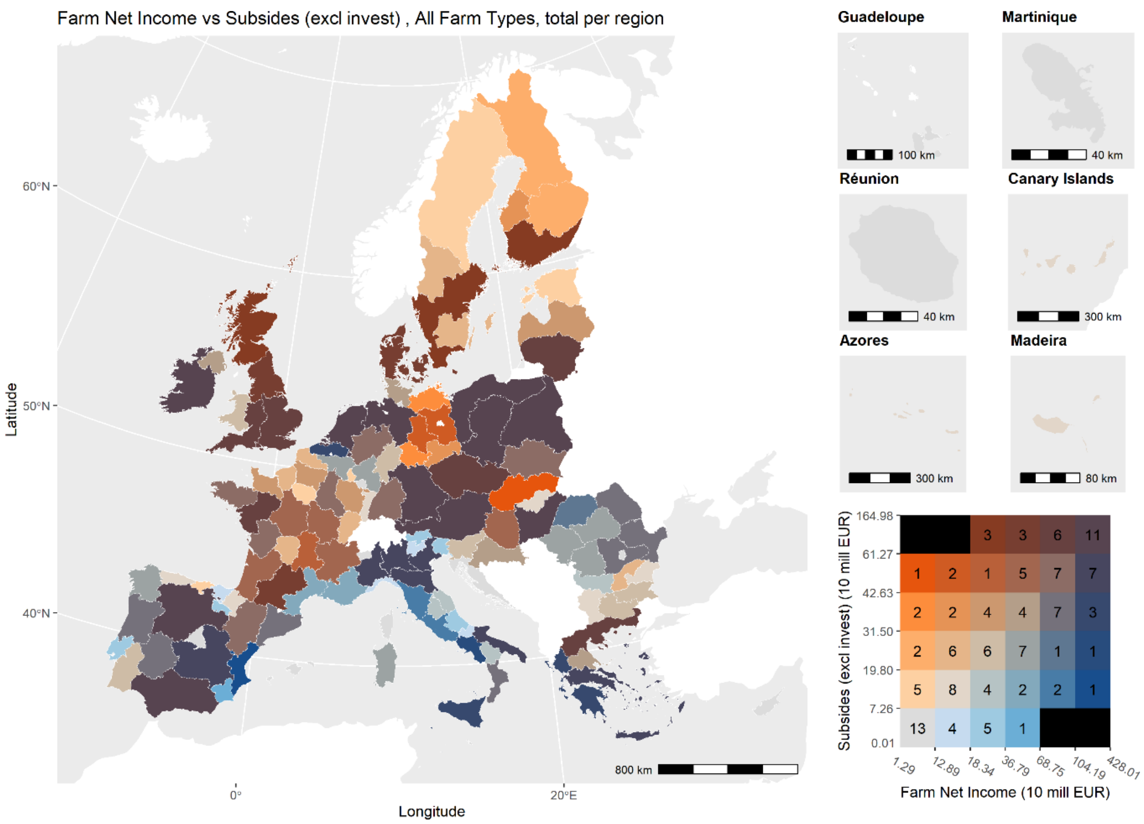

Figure 47: Farm net income versus subsidies.

The conclusion from this analysis is that in strictly viability terms, there are some agricultural production systems that have very little dependence on CAP. In some cases, these are production systems that have had limited exposure to subsidy (horticulture and specialist granivores) and are thus financially resilient, since otherwise they would simply not exist. Yet the concern with such production systems is that in achieving this financial independence, their environmental and social sustainability can be called into question. Thus it is possible to hypothesise that CAP may be both a financial safety net that allows for the continued existence of inefficiently-managed businesses but that simultaneously the CAP provides governments with levers to generate more positive (if limited) outcomes for the environment, welfare and employment.

3.4.3.2 CAP subsidy links with labour and capital

The analysis of the role of the CAP in underpinning viability can usefully be supplemented by relationship mapping for how CAP spending links with labour and capita (buildings and machinery). Here the analysis aims to identify where the CAP has a greater role in maintaining employment and where in aggregate the CAP may be financing, or underpinning the financing, of more capital-intensive production systems, potentially reinforcing the long-term trend of declining labour use. Figure 48 highlights that any relationship between CAP subsidy and labour used within agricultural production systems is complex, but also that there are distinctive regional partners (eastern versus western Germany), some associated with Members States (e.g. Poland and Romania). The map highlights those regions with higher CAP subsidies relative to the labour used (lighter oranges) and those associated greater labour use (lighter blues) against what is a broadly positive relationship between CAP spend and employment (the centre diagonal in the legend).

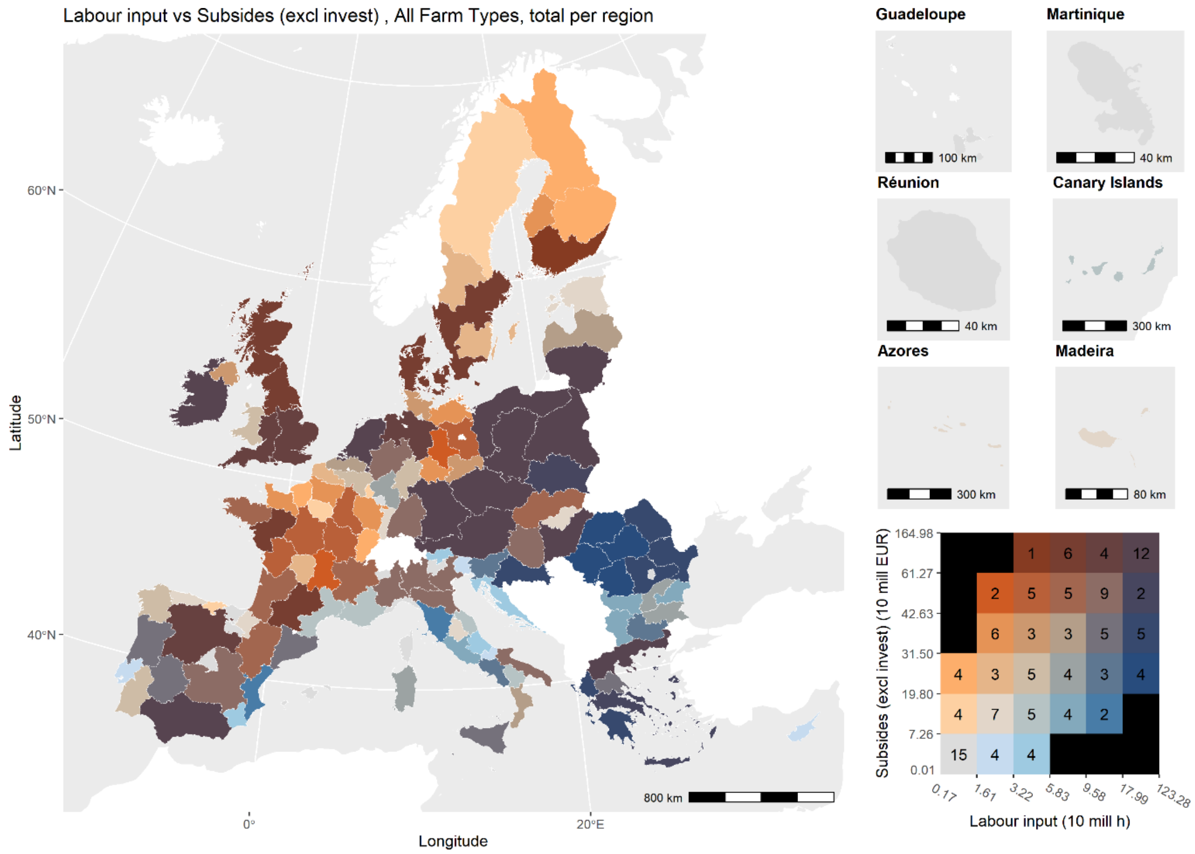

Figure 48: Relationship map of labour input and CAP subsidies

Figure 49 presents an equivalent analysis for the capital used by production systems. This highlights those regions where there is a greater use of human capital funds within the production systems. Regions with higher subsidies, yet lower use of infrastructural capital include several regions of France, Spain and Bulgaria. Regions with higher rates of use of capital relative to subsidy include central Italy and Romania. Otherwise there is also a positive relationship between subsidy and use of infrastructure capital with higher levels, both in the productions systems of central Europe, Andalusia, the Netherlands and eastern and western England.

Any policy such as CAP that seeks to achieve objectives of both competitiveness and maintaining or enhancing employment in agricultural production systems quickly runs into contradictions. Historically, increased competitiveness has been achieved by deploying capitals that eliminate labour within industrial production systems. For agricultural production systems, such labour has been more productively deployed in other sectors. Pressure for competitiveness and low-cost production may also mean that even where CAP subsidies do generate employment, the quality of the employment provided (seasonality and wages) can be so low that it can only be delivered by imported labour from beyond the EU boundaries.

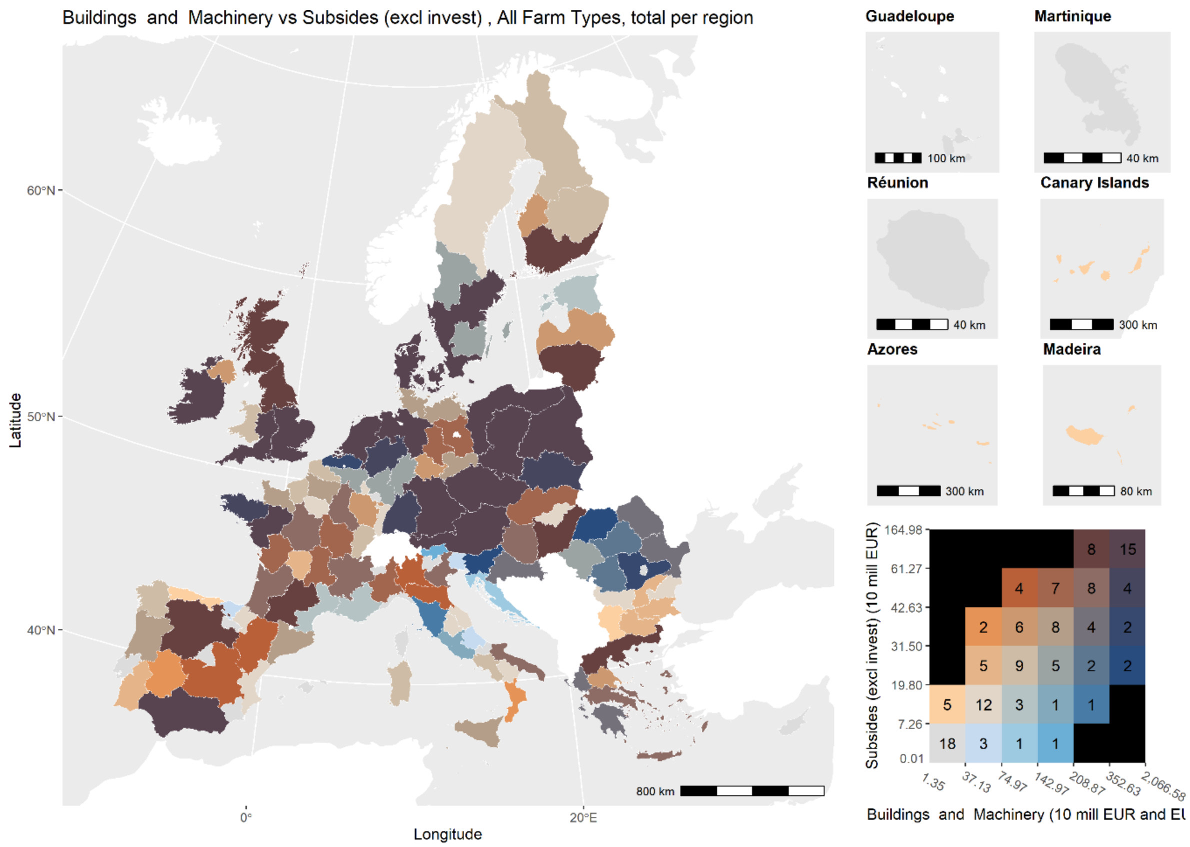

Figure 49: Relationship map capital (buildings and machinery) and CAP subsidies

3.4.4 Supply systems

Earlier results have emphasised that understanding how the EU is achieving the objectives of SDG2 means the need to look at agricultural production systems, but in the context of supply systems and societal demand. The ambition for this deliverable was to fully elaborate the use of embodied (e.g. land, labour and water) resources in imports and to assess the draw on EU resources implied by exports. It has not been possible to conduct all the analyses desired within the deliverable deadlines so what can be presented is a partial analysis with examples drawn from work in other parts of the

MAGIC research programme. With the data in hand, some of these analyses may be more fully realised in work within further MAGIC dissemination activities.

3.4.4.1 Openness and externalisation

One of the key insights from a range of societal metabolic accounting is the degree of dependence of the EU on imported resources. These flows of commodities imply the use of funds (land, labour etc) beyond the EU's boundaries but also a footprint of environmental impacts. These may be severe when production systems beyond the EU are not conducted in ways that would be considered acceptable within the EU (for example the clearing of rainforests). This implies two measures of performance that can only be considered at the level of supply systems – openness (the sharing of resources used in a system) and externalisation (the reduction in pressure on local funds). The former has implications for food security, since assumptions of only moderate scarcity of resources may not apply in the medium term. The latter has strong implications for how any assessment of EU environmental sustainability is assessed since any current accounting e.g. of GHG emissions or soil/biodiversity loss, ignores the footprint of imports. This is an incentive to achieve greater apparent sustainability simply by reducing local intensity of production with any deficit in societal demand being made up by imports. These issues cut across the objectives of SDG2 both within the EU and in trade partners and imply complex policy trade-offs and governance challenges.

3.4.4.2 Trade and implications for food security and sustainability

One example of such policy challenges relevant to SDG2 is food security. Here the pattern of imports and exports can be interpreted in social metabolism terms. Figure 50 shows in a chord diagram, as physical flows (tonnes), the relative magnitudes of imports, their type and their sources. The figure highlights that in physical terms most imports are of animal feedstuffs (oil meals, oilseeds and maize), with more limited imports of commodities potentially directly consumed by humans (wheat and sugar). In terms of sources, these are dominated by south and north America, though for vegetable oils (palm oil), south-east Asia is the key source. Within the EU, a key source of agricultural commodities is Ukraine and given political and military circumstances, reliance on such supplies has clear food (and other) security implications. In many, or arguably all, of these cases, these production systems generate low cost commodities but using systems of production that would not be considered acceptable within the EU. As noted in earlier sections, these imports also mean that livestock production systems within the EU can achieve higher intensities of production but potentially at the cost of local environmental impacts from waste.

Figure 51 presents EU exports using the same form of diagram. The figure highlights that in terms of commodities, the EU is in the main an exporter of food for humans rather than animals. Cereals makes up the bulk of exports in terms of tonnage, although the tonnage of dairy product (as milk equivalents) is also substantial and has a much higher financial value per tonne. Exports in the main are to north Africa and the Middle East, but there are also substantial exports to sub-Saharan Africa and less developed countries (LDCs), mainly of cereals.

Exports to south-east Asia and China have larger proportions of dairy. Barely is prominent, with a role in religious dietary requirements in some regions and for brewing elsewhere. Increased exports from the EU have been seen as evidence of greater market orientation and efficiency but this is hard to square with the destinations and the financial performance of the specialist cereal farm type (see Section 3.4.3.1). In terms of food security, it is likely that EU food production will be significant in maintaining global food availability in terms of both quantities and price for trade partners. Yet for exports the environmental footprint is internalised in any assessment

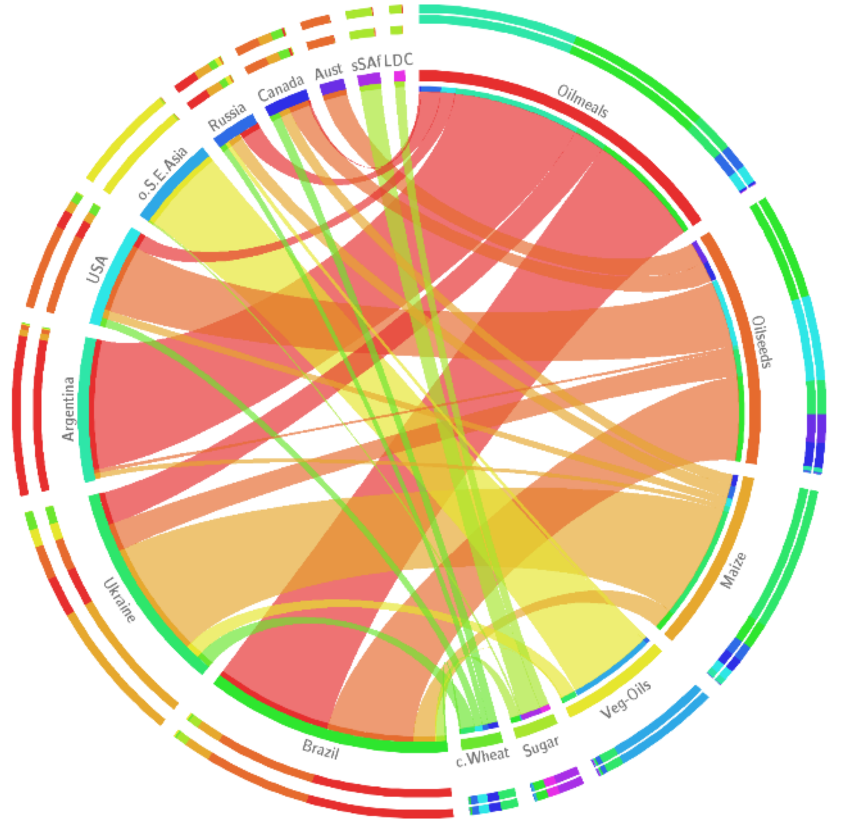

Figure 50: Imports to the EU (tonnes)

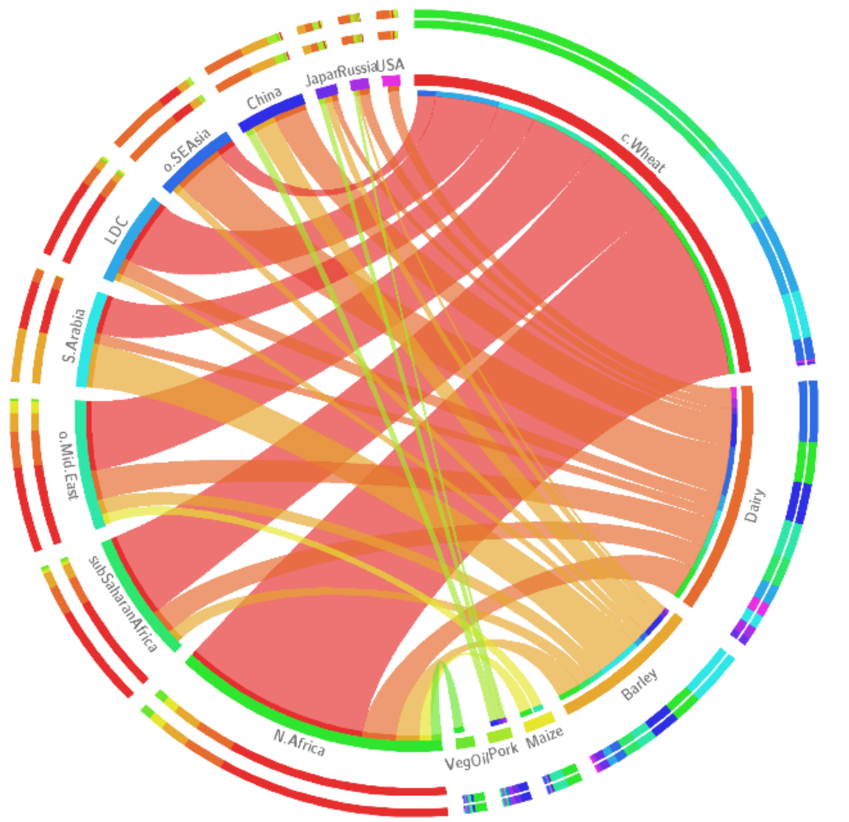

Figure 51: Exports from the EU (tonnes)

3.4.4.3 Reinternalisation

For imports, the estimation of the actual footprint in terms of land, labour or environmental pressure can be extremely challenging. In this analysis it has been possible to make estimates of the magnitudes of imported feeds being used by specific agricultural production systems, regionally (see Figure 39), and sectorally (Figure 52)[16]. The sectoral analysis highlights greater dependence of granivores on imported feeds compared with grazing based systems, even those more intensive systems like milk production.

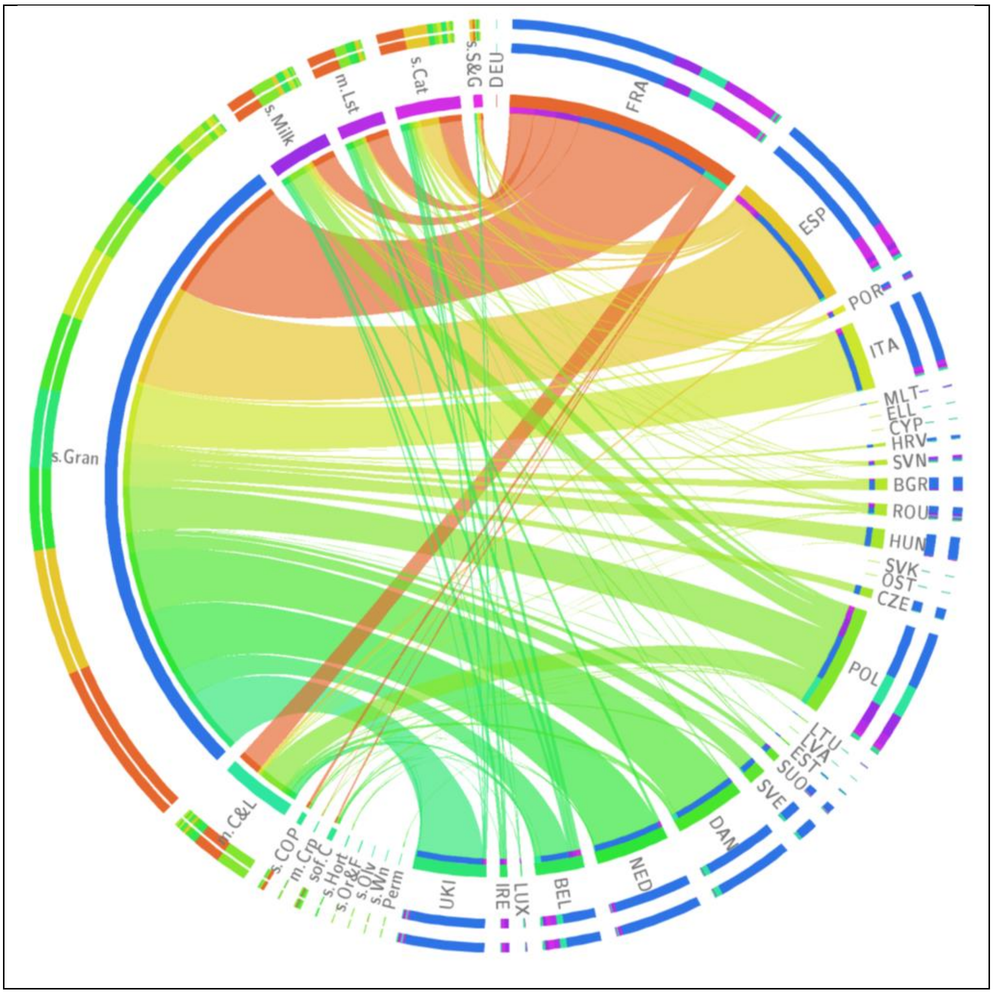

Figure 52: Use of imported forage crops - tonnes 2014-17 by Member State and farm type

For sustainability assessment of these patterns there does however remain the key issue of attributing the materials used to a source. This is significant when materials may have very different environmental or other fund footprints (e.g. soya from USA compared with soya from Brazil).

While absolute values for the footprints of imports remain challenging, an alternative approach that generates information relevant to both to food security and environmental sustainability is to assess the local funds that would be needed to reinternalise imports. Such an approach uses the magnitude of commodity flow and translates these into local fund requirements using the rates of resource use within the EU (i.e. local benchmarks). An example of such an analysis has already been presented for

[16] The data on which the analysis is based, while the best available, was still unreliable in several cases, most notably for Germany. The analysis has highlighted several areas where the analysis can be improved on but is included here as a marker for the kinds of analysis that could be conducted and their potential utility.

the blue and green water in imported animal feeds (Figure 35). Analyses for land and labour will also be undertaken, but examples of such analyses have also been generated elsewhere within the MAGIC project (Cadillo-Benalcazar, Renner, and Giampietro 2020; Renner et al. 2020 in press). Figure 53 presents the use of land embodied in imports, while Figure 54 presents the use of embodied labour in imports. For Figure 53, the amount of land is presented relative to that available within the Member States. What is clear from the figure is that across the EU there is a substantial reliance on land beyond the EU that means, without profound changes to agricultural production systems, it is not feasible to reinternalise the commodity flows using local land funds. The highest values associated with the Netherlands and Belgium reflect substantial use of imported feed but note that that the analysis does not account for re-exports to the rest of the EU, with the commodities being attributed to the Netherlands and Belgium by virtue of their hosting major ports of entry in Rotterdam and Antwerp.

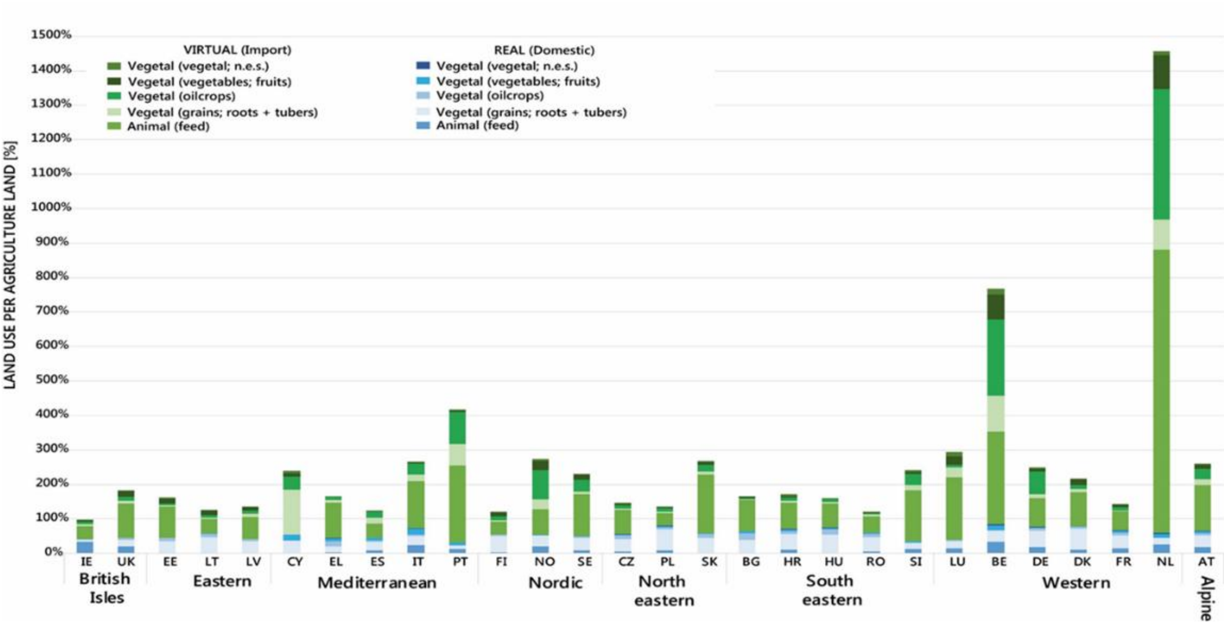

Figure 53: Use of land funds beyond the EU embodied in imports (from Cadillo-Benalcazar et al. 2020).

For embodied labour in Figure 54 the pattern per Member State is substantially different, reflecting relative rates of productivity per person within agricultural production systems. The figure shows the per capita requirement for labour (a measure of intensity) with the extent of requirement estimated as a function of population size and average number of hours worked per annum in the sector.

The intensity measure was preferred here since it emphasises better the degree of challenge that any reinternalisation would bring for Member States. It is worth noting here that the implication of these results is that any substantial reinternalisation of production would make demands for labour that could not be met within countries without diverting labour from other activities and that any production would be very unlikely to be able to match the prices of imports given minimum wage value within the EU and environmental standards.

These are the main quantified stories that were generated by this QST cycle, using metrics generated from the complex MuSIASEM processor to consider to what extent EU agricultural systems can be seen to be biophysically feasible or socio-economically viable; and whether the outcomes generated in 2014-17 match the desired outcomes from CAP and other policies (WFD, Natura 2000), and will help the EU to progress towards SDG2, particularly the target for sustainable agriculture (see Table 1). The next section covers the stakeholders' reactions when the headline results were presented.

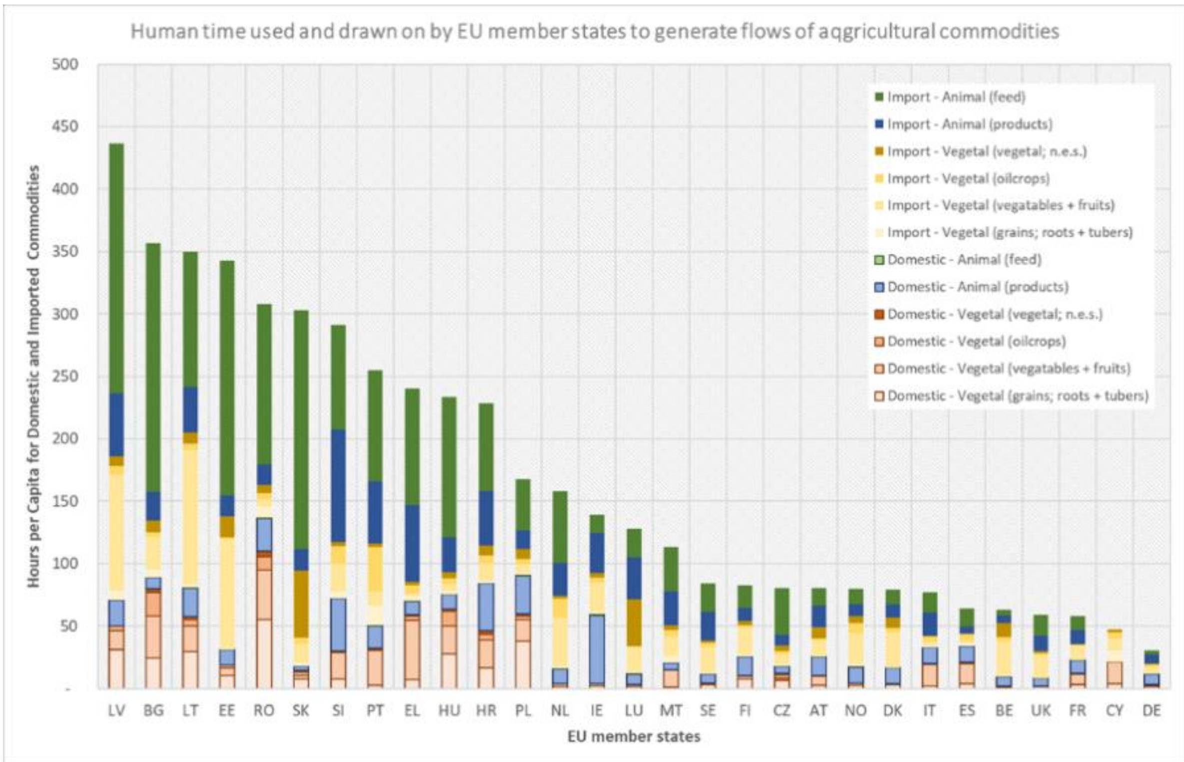

Figure 54 Use of labour funds beyond the EU embodied in imports (from Cadillo-Benalcazar et al. 2020).

3.5 QST Stage 5: Closing the loop with stakeholders

This section covers the authors' views of the implications of the SMA analysis before turning to an analysis of what the data suggests about how the policy actors viewed QST, the quantified results and the salience to policymaking. As noted in Section 2.4, the results presented in Section 3.4 are more detailed than those presented in the stakeholder engagement events (see Appendix III: Slides presented when closing the QST Loop). This section also presents the limited evidence elicited from stakeholders regarding our overarching question (the degree and nature of policy change(s) required to be compatible with the EU's sustainability goals, as expressed in SDG2 and its interactions) before identifying some emerging paradoxes. It is important to note that improvements to the accounting framework and visualisation of the metrics continued until June 2020. Thus, some of the results presented in Section 3.4 were not available, in the new Chord diagram or relationship map formats, for our stakeholder interactions. However, whilst the content in Section 3.4 is more sophisticated and extensive than that presented in November 2019, January 2020 or early June 2020, the overall messages were the same.

3.5.1 View from the scientists on the implications of our analysis

During 'closing the loop' of QST cycle interactions, described in Section 2.6, the presentation finished with a slide highlighting how the MAGIC scientists interpreted the SMA metrics. This tried to contextualise the scientists' interpretation within current policy debates such as the development of CAP post-2020, reporting on progress to SDG2, the proposed Farm to Fork Strategy and the proposed Green Deal.

The conclusion was that the European agri-food system needed to change to be sustainable, particularly in terms of environmental pressures within and beyond the EU in terms of embodied water, energy and nutrients. It was argued that individual policy instruments tended to focus at the level of ‘production steps’ or ‘sequential pathways’ (see Figure 55) but MAGIC aimed to consider the overall ambition of SDG2, as supported by CAP and other policies, which meant trying to understand the interactions between all five analytical levels.

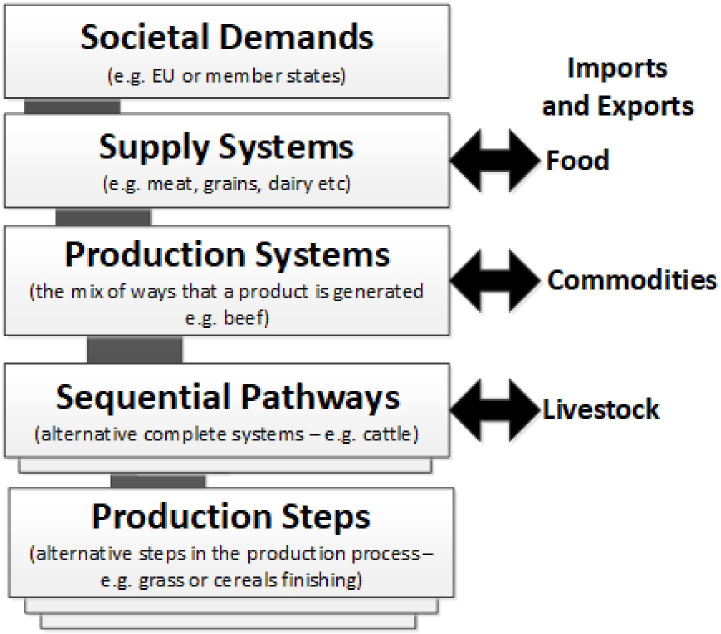

Figure 55: Levels of the SDG2 SMA analysis

Methods such as MuSIASEM were suggested as useful for complementing and extending existing metrics in use by EU institutions (e.g. EEA, EC, JRC, Eurostat) to ensure that the full picture was considered, including both extent and intensity, and connecting both production and consumption systems. As part of this, the importance of considering ‘societal demand’ in setting expectations of what and how the agri-food system delivers were emphasised. This recognised the importance of the Farm to Fork Strategy to achieve this, and the need to think about the roles of consumers and citizens in delivering SDG2. Finally, the scientists confirmed the importance of policy coherence, quoting the Commission’s policy. However, the societal metabolism metrics presented suggested that CAP has not yet helped achieve its own, let alone other, policy objectives e.g. from the WFD.

Our statements were qualified with open questions regarding:

1. Given the environmental pressures are unlikely to be sustainable within and beyond the EU, are these justified by social outcomes of agri-food system? and
2. To what extent there was an appetite for the EU to develop a food policy?

The presentation ended with a final question that acknowledged how our analysis was not the first critique of sustainable agricultural processes in the EU, so the call for change should not come as a complete surprise. Participants were invited to share why change was proving difficult.

3.5.2 Participant views on MAGIC’s semantic methodology

A few participants showed awareness that the project’s overall work entailed trying to understand and respond to policy narratives and stakeholders’ views. Doing so was seen as rare but positive: *“the first time to include policymakers into this kind of scientific work is essential. It’s a very good step forward...”* (YR, DG Agri). In 2019, an interview about the SDGs with an advocacy NGO also noted research to demonstrate policy coherence by the Commission is “*just lacking*”, supporting the need for policy analysis to complement and link with the formal SMA methods (JR). These discussions in spring 2019 also supported and informed the choice of SDGs as a salient focus, though not necessarily or exclusively SDG2.

The final choice of theme used in this phase of QST (Section 3.2) rarely received explicit comment during the final events and discussions with stakeholders in late 2019 and early 2020. However, our ability to recruit and communicate stakeholders linked to European policy, many of whom were not already involved in or aware of MAGIC, is perhaps the clearest indicator that our focus on SDG2 was salient. This is true for each of the three main engagement events of Phase 2, which together encompassed different roles in European policymaking.

Firstly, our November 2019 event, which mainly targeted individuals within the Commission, resulted in 15 participants from more than one DG. This relatively high turnout suggests interest in systemic methods and SDG2 that spans multiple policy domains/units. The comments made during and after that seminar also did not comment on or question the theme itself, but instead tended to ask for more specific insights e.g. on extra-EU impacts, recommendations about how they could change policy to support sustainability, or suggested that we could not consider issues such as food consumption where there were currently few policy levers. Although we could not satisfy these requests, the concerns can be read as demonstrating desire for change – albeit sometimes only within the scope of current policy processes.

Secondly, our ability to run the Parliament breakfast in January resulted from the host MEP quickly accepting our proposal topic, and then being able to recruit several attendees linked to the AGRI parliament committee. Both factors again suggest the theme was politically salient at least with the more green or liberal groups such as Renew Europe. Questions arising in that discussion suggested specific issues to help make future policy more sustainable, including the effect of banning pesticides, population growth trajectories and biofuels. Participants did however remind us that the media and public can push what politicians focus on, often preferring campaigning on single issues rather than engaging with complex issues or the need for large-scale systemic change.

Lastly, the webinar with the EEA in June 2020, was held at their request, partially resulting from interest spurred by prior events or interactions with a MAGIC staff member. The discussion within this webinar was more focused on how the method could be adopted and connected with other methods used by the EEA. This suggests that the topic, and the need for new methodological perspectives on it, is almost self-evident or 'taken for granted'. For this audience at least, the need for change was accepted. "*Whenever we look deeper into these things" – whether through MAGIC or through pre-existing data and methods – "we are pretty [expletive]*" (PM, academic).

3.5.3 Participant views on Magic's formal methodology (SMA)

This section appraises participants' views and responses to the concept and principles of the formal aspects of QST i.e. Societal Metabolism Accounting.

The practical ways we communicated our material – the presentations used, the balance of material, the audibility of speakers, the structure and organisation of events – were all well-rated by participants who offered feedback on these issues, except for one (PL, DG DevCo). However, our interactions with participants often did not result in their having complete confidence in the details of SMA and its outputs, especially for those individuals who only attended one MAGIC event or had only one interaction with the material. This may have partially resulted from introducing novel terminology – which was accused by one participant of being "*cumbersome*". As with most analytic approaches, the SMA method is accompanied by its own language (see terms introduced in Section 1.2), but it might have been possible to use more familiar terminology. Furthermore the "nexus" concept and language used by MAGIC was not something used or deemed particularly useful by participants. Challenges in communication may have been inevitable, given the complexity of the method and its outputs. For example, PL expected she would need at least a day's workshop to answer all her questions; whilst GR has attended a week-long summer school on societal metabolism. Spending more time with these participants may not have been feasible within their current schedules – the feedback interview with YR described how little time they had to attend events or read material.

An incomplete understanding of MAGIC is an important influence or constraint on some participants' responses or reactions, meaning they found it hard to 'digest' the material and thus to see implications. For example, AH in EASME, when requested to return the feedback form after the November 2019 event, said "*Although in principle I am always willing to provide feedback, I think this time I am not able*." One participant's feedback interview wanted more interaction and responsiveness, e.g. after the November 2019 event, which they said would have further promoted comprehension. However, even if they were not yet completely confident of the details, most participants felt they did understand the key principles enough to make some judgement of the method.

SMA was generally considered to be "*interesting*", and several perceived it to have strengths that complement other existing methods in use. Interactions with participants from the EEA specifically praised the method for dealing with socio-ecological systems complexity "*in a proper way, so it's very insightful*" (PM). The specific features or aspects of application that were valued often connected with participants' skills and policy focus. Comments from participants in the breakfast seminar liked its "*multi-dimensional view*", i.e. allowing appraisal and connection across levels. A feedback form jointly completed by DG DevCo colleagues EG and MR also supported the concept of funds and flows. YR, an agricultural economist, similarly thought societal metabolism was "*good food for thought*", liking the concept of flows, and perceiving it brought more attention to societal issues, whereas other methods were stronger on environmental and economic issues. Interviewees who helped frame the QST cycle (KS, JRC; SD, DG Agri; JR, NGO) and fieldnotes from the EAAE meeting also suggest that methods need to balance interactions across all three pillars of sustainability.

BD (DG Clima), who worked on climate policy, perceived it could show the "*full consequences*" of agricultural activities, whilst offering more "*useable*" insights than other existing methods such as Life-Cycle Analysis (LCA). GR and PM, who support environmental data analysis for the EEA, similarly thought the method could have value in enabling systems thinking and analyses. However, seeing exactly how the method could be applied was not clear to any participant. BD was very positive about the method and said it "*triggered very quickly... a familiarity of how it could fit in which, the work we were doing*" and could eventually "*create space*" for discussions on mitigation via land management. However, even BD said he would require "*more time and interaction*" to use and apply SMA, a theme repeated by YR (both DG Agri). Related to this, several participants raised questions about the pros and cons of SMA versus analytic methods such as LCA that are already used to support policy. An answer to this was not completely articulated during the interactions but a subsequent reply was provided in June 2020.

As mentioned above, EG was positive about some aspects of SMA: however, they also critiqued MAGIC for not providing more specific insights or recommendations that were actionable by policymakers. EG also suspected the project's analysis did not recognise the complexity of the "*Brussels machinery*". This desire crossed policy domains. Stakeholder LA, from DG Env, who was interested but could not attend the November event, wrote to say they only wanted to receive outputs directly relevant to soil policymaking. Questions from GR after the EEA webinar also queried how far the outputs could be linked to CAP policy and how the link could be made. We had carried out analyses of policy coherence (see Section 3.2) and furthermore thought our SMA application was policy-relevant, but clearly this was not obvious to the participants with whom we discussed the phase 2 outputs.

Frustrations with a lack of applicability may also result from trying to illustrate many issues with a diverse audience: tailoring presentation and discussion to one individual or team might be more successful in connecting the work to current policy processes. However, MAGIC and the phase 2 presentations aimed to prompt reflection on the feasibility, viability and desirability of narratives that underpin current policy, not to provide immediate solutions to current policy problems. The next section reflects on the extent to which we achieved this.

3.5.4 Participant views on MAGIC's quantified results

This section focuses on participants' responses to the quantified SMA *results* and other outputs that arose from our application of the method, rather than the principle of the method itself.

Many participants had said that they found the method interesting or intriguing, and during in-person interactions all participants appeared to be following the results closely, and so it seems our results were actively considered by them. Only two commenters expressed overt disagreement or negative views about the results. Firstly, SD (DG Agri) explicitly disagreed with the implications identified (Section 3.5.4) and accused us of being unfair in the issues or cases shown, and our conclusions not being supported by robust evidence. On a slightly different note, GR (EEA) commented that "*the new narrative in our institution is that we are all looking solutions to sustainability challenges. And then, as it often happens in science, you more often find disproof of certain theories*". They were not necessarily disagreeing with our results but were observing that it is easy to find flaws in existing thinking, data, or processes, without this necessarily being constructive or balanced.

All the other responses about the implications of the work were generally positive about what it offered for understanding and achieving more sustainable agri-food systems, implying that change of some sort is needed to achieve sustainability. For example, an email from DW in DG Environment, thought our work made a "*useful contribution to the issue of how to make our food system more sustainable*". However, such comments were quite general, not specifying exactly the additional specific insight or implication that MAGIC had triggered. The feedback interview with GR suggested that the material we presented in the seminar highlighted "*tension*" or criticisms of current policies and policymaker efforts, which is in line with research teams' intent. No stakeholder however elaborated specifically what policy instruments or processes were problematic or need to change. The responses to our material at the Parliament breakfast were more visceral, including responses from one MEP that the situation was more "*scary*" than they had understood, and an observation that much of the work of the Agri committee was adjusting relatively minor issues that did not engage with the scale of change needed to achieve sustainability. Another MEP suggested that the Commission should be more radical in the proposals that it presented to Parliament in future.

The feedback forms distributed after the November 2019 event (Appendix I, page 130) specifically asked participants to rate the implications of our results in terms of biophysical sustainability, social and technical sustainability and cultural and political sustainability (i.e. the QST issues of Feasibility, Viability, Desirability (see Section 1.2.3)). Only three forms were returned; and of these only two completed the ratings. AH in EASME had rated all aspects as "*somewhat*" sustainable within and beyond the EU (the second option on a four-point scale from "*not at all*" to "*completely*" sustainable). The other form, jointly completed by EG and MR in DG DevCo, rated all aspects as "not at all" or "*somewhat*" sustainable, with the exception of the social and technological sustainability of agriculture within the EU, which was rated as between "*somewhat*" and "*mostly*" sustainable. They commented that the current EU agri-food system "*overlooks too easily its externalities*", especially in relation to natural capital and non-EU countries.

However, beyond the Parliament breakfast and the responses described above, most participants with whom we interacted did not offer any view on the implications of our results, despite our attempts to prompt on this.

3.5.5 Participant views on salience of MAGIC to policy

As stated above, our participants made relatively few direct comments about the implications of our QST application. Our data suggests that individuals were considering the findings in context of their niche in existing institutions, and their role to oversee current policy, rather than identifying or advocating transformative change. For example, some participants variously argued that the findings reflected a global agri-food system problem, which was beyond their (personal) jurisdiction, that food policy was not an EU competence, or that we should speak to DGs other than their own. However, reading across our data we do identify specific topics and ways in which QST and policymaking may connect. The following Section (3.5.6) discusses why we did not receive more direct comments on implications.

In terms of SDG2 and the CAP as a WEFE nexus policy, participants identified some specific areas that could also be further investigated through QST. These included:

1. a more explicit focus on energy (GR);
2. comparing the SMA results with the recent CAP impact assessments (YR) and the CAP monitoring and evaluation framework, possibly highlighting areas "*not sufficiently covered by the CAP*" (GR);
3. climate change, in particular in relation to land use (BD);
4. waste and the circular economy in the agri-food system (JR);
5. integrating action on biodiversity and climate change (BD); and
6. as a tool to integrate findings from other Horizon 2020 and EU Life projects researching agroforestry, carbon sequestration in soils and animal systems (BD).

BD also suggested that the approach could help understand rebound effects and stakeholder engagement about greenhouse gases within agriculture for national climate and CAP plans, while GR additionally pointed to the WFD and Farm to Fork strategies as areas to engage with in the future. Considering the Commission's proposed Green Deal, YR referenced the language of "*planetary boundaries*" and suggested that SMA could help identify such boundaries. However, as discussed in Section 3.5.4, these participants did not comment on where pre-existing work had already illustrated crossing planetary boundaries (see Section 3.4.2), nor policy responses.

In terms of all the SDGs, our Green Week fieldnotes highlighted a widespread interest in analysing system lock-ins, such as infrastructure and social attitudes to enable policymakers to tackle these challenges. One source suggested that QST could include an analysis of what practices need to be *stopped* to achieve the SDGs, rather than just focusing on new practices needed to move forward (JR, NGO). EG, who works in development policy, thought the "*international dimensions*" inherent to the approach might be able to usefully illuminate and emphasise the consequences of EU actions on other places, in support of policies to "do no harm". The role of the UN in the SDGs, and differences between issues addressed at the UN's HLPF (High Level Political Forum on Sustainable Development) in New York and the UN Environment Programme in Nairobi also has implications for taking forward policies to achieve SDGs. JR (advocacy NGO) articulated how the people attending meetings in New York are often representatives from the Economic and Social Council, whereas Environment Ministers are more likely to focus their energies on events in Nairobi. JR's concern about the dominance of economic thinking in New York circles was replicated elsewhere, and participants expressed interest in the use of QST's accounting terminology and its 'scientific framework' to describe environmental and social impacts in a way that might resonate more clearly negotiating on a global stage.

A broad 'scientific framework' to appraise new policy initiatives was mentioned by several participants. For example, YR (DG Agri) thought MuSIASEM was especially useful to appraise social issues in the context of sustainability, commenting that social issues were often harder to articulate than economic or environmental consequences of policy actions. The ability of QST to analyse whole systems was also particularly noted by MEPs at the Parliament breakfast in January 2020. One MEP commented that QST might have enabled identification of the problems with biofuels, before the EU policies in the early 2000s sought to heavily promote them. BD (DG Clima) expressed a similar concern about oversimplifying complexity in making climate change policy. BD gave the example of targets being set for emissions reductions and the need to fully understand the implications of those targets for how society operates. Another example offered by BD was the current focus on tree-planting as a climate-friendly action, despite some known concerns, suggesting QST as a potential method to help show the system-wide consequences of such policies. These policy areas of course reflect the types of issues that participants are addressing in the context of their current work, which may change over time. Thus, the potential salience of the method was recognised but, in most cases, participants wanted to reduce the focus from the overall system to a specific policy instrument or element in the system (e.g. climate or water, rather than the overall systemic interactions).

A tool for communication with policymakers. Despite the challenges of communicating with and about QST (see preceding sections and Section 3.5.6), a few participants thought it could be useful as a tool for helping to articulate complex systems clearly to policymakers. GR (EEA) discussed how QST could potentially help identify "*unintended consequences*" and "*blind spots*" in policy areas such as energy, food and agriculture. BD (DG Clima) described QST as "*the tool that we've been missing*" for understanding complex policy issues: "*it's not that I sort of sat there thinking, 'how can we use QST in our day to day work?' It was more sort of mental note that this is a tool that we're missing…".* YR (DG Agri) indicated that specific aspects of the QST methodology were particularly relevant, identifying concepts such as accounting and flows, with an indication they were trying "*to introduce these concepts of flows into my own work…*" and discussing how "*getting an idea of the boundaries or constraints…could help to, let's say, define the constraints, limits or boundaries of certain policy options or decisions*". GR similarly indicated that in their policy context, they were now adopting concepts introduced through QST such as "*the need of doing analysis, the viability, feasibility and desirability…*"

Reinforcing the need for policy coherence. The issue of policy salience cannot be fully investigated without an acknowledgement of the complexity of EU governance systems. Indeed, these insights bring together geographic issues of multi-level governance and shared competences between EU and Member States and the EU in international/global governance institutions. Some participants pointed out that the very nature of the SDGs means they are 'owned' by Member States rather than by the EU (even though the EU has also signed up to the 2030 Agenda and thus has a responsibility to implement the SDGs in its legislation). This tension is repeated for SDG2 and CAP, where the EU institutions set out steering frameworks such as budgets, overall instruments, and evaluation indicators, whilst the specific mix of instruments and spending remain the responsibility of each Member State. Furthermore, SDG2 and CAP has implications for both EU-internal and EU-external policy. A participant from JRC (KS) pointed out that it was compulsory for the Commission to use external affairs policy to address SDGs, but this was not (yet) matched by such a policy internally.

Although trying to be more cross-cutting in their approaches, participants commented that the EU institutions still struggle with silo-governance. A participant at Green Week (2019) indicated that working across environment, agricultural and development sectors was challenging. Within EU governance structures, different DGs have responsibility for different SDGs, and despite initiatives like interservice groups (see Section 3.2), policy coherence for internal EU policy, remains a work-in-progress (SD, DG Agri). Indeed, external participants were more critical, suggesting that QST was seen as a useful approach because it is a scientific approach that "*shows that [policy] coherence is just lacking…*", both with regard to EU policies towards the global south but also regarding the need to transform within EU policies and social practices (JR, Advocacy NGO).

3.5.6 Why was there limited feedback on implications of the QST results?

Although Section 3.5.5 illustrates an appetite for QST in EU policymaking in the future, overall, there was relatively little feedback or discussion about the implications of the results on the overall sustainability of the EU agricultural system, either in terms of changes needed for agri-food systems, policy or wider society. Given that we received few negative comments about the principle of the method, and had apparently attentive audiences, why did we struggle to elicit reflection on this 'big picture'? The remainder of this section explores why this may have occurred, despite our intentions.

How we applied SMA. Whilst there was general agreement and support for the overall issue which we explored in phase 1 and 2 of QST (Section 3.5.2) the specific issues and detail of application could affect how it was perceived by participants and thus how able and willing they felt to react to the results. As noted above, participants varied in the specific angles that they wished for more detail. There was a strong interest in seeing more detail on the externalities of European agri-food systems, and in particular, EG in DG DevCo asked for more specificity in both the data used to explore extra-EU impacts, and in our implications and recommendations. Other issues raised included more detailed exploration of the agri-food system beyond the producers, e.g. the role of processors and retailers. Participants in the Parliament breakfast mentioned it would be useful to have insights focused around the effects of changes in biofuel use, pesticides application and population growth. PW at this event asked us to substantiate references to improvements in efficiency not always being helpful.

How we communicated SMA. Of necessity, within the space of one interaction we could not communicate all details of our methodology and every possible result arising from applying it. Instead, we attempted to communicate the principle of the method and some specific vignettes or snapshots arising from it, as an illustration of the method's approach and potential. It is possible that this broad approach was less likely to spur distinct advances in participants' existing views on agri-food systems. Had our work offered more detailed insights on a subset of issues, more specific or distinct implications might have been easier for participants to articulate. Furthermore, more detailed consideration of health, social justice and equity – issues raised in our SDG interviews and noted in other events – may have aided recruitment and responses from other stakeholders such as DG Santé. However, covering all these issues would have been challenging in the space of our main engagement events, given participants' differing interests. Indeed, some of participants' requests were directly in tension: DW asked for more attention to demand in the food system, which is in tension with EG's request to focus more on issues amenable to current policy levers. The only way to handle all these interests and requests would be to separately pursue engagement and tailor analysis to different individuals.

The way in which we communicated – not just what we communicated – may also have affected responses on implications. As noted above in Section 3.5.2, we were generally seen as communicating well, although explaining a complex method such as SMA was inevitably challenging and could feel 'hard to digest'. However, GR believed that the style of MAGIC's presentations – considering experiences with the project beyond our work in phase 2 – tended to make "*harsh*" assessments of main narratives, that "*touched a nerve*" with participants trying to work on and improve existing policies. Instead, a more "*diplomatic*" approach was needed for participants not to react strongly against the project and its findings. Participants were not necessarily expecting to openly discuss the pros and cons of their policies to the extent that we hoped.

Suggestions from several participants noted the need to communicate the historical reasons for policies and their change, and contextualising current data. This could presumably assist in demonstrating that we understood the drivers and obstacles to policymaking, as well as understanding the particularities of our data. Lastly, appraising the pros and cons of alternatives, not only critique, could assist in the MAGIC project being seen as constructive. But once again, communicating all this within the limited space of interactions, is challenging. Diverse participants themselves showed recognition of this: GR (EEA), YR (DG Agri), PM (EEA European Topic Centres) and EG (DG DevCo) all said they would like more follow-up to understand and see applicability to their own work. Such interactions may also tend to encourage more explicit reflection on how the method and outputs add to or update their views, and their implications.

How we organised and structured interactions. Closely related to the issue of how we communicated our method and data, are the settings in which we organised interactions, and the questions we asked of participants. Our work to apply QST and discuss the results was explicitly designed to prompt discussion on the implications of the results. For example, the slides shown in the November 2019 seminar explicitly asked for participants' views on implications, after stating our own view that policymaking needed substantial change (Section 3.5.1). Despite this, within the main event that is the focus of phase 2, the November 2019 seminar, the questions and responses after the main presentations tended to focus on questions about the data and application of the methodology, rather than remarks about the 'bigger picture'. Feedback forms we were provided, and our own post-event reflection indicated that tweaking the format of our engagement to give more time and emphasis on discussion may have allowed more reflection on this. But planning a longer event would likely have negatively affected recruitment. As noted above, we might have planned more individual interactions, perhaps as follow-ups, in which there would be more opportunity for this reflection: yet in the feedback interviews of 2020, this issue still did not arise.

Our participants, their backgrounds and expectations. In summary, our November 2019 event targeted mainly those working in the Commission; the January 2020 Parliament breakfast targeted mainly MEPs and their support staff; and the June 2020 EEA webinar was aimed at staff members and external individuals supporting EEA work via European Topic Centres (see Section 3.1 for more information on whom we targeted and were able to engage with). In the November 2019 event we noted that more junior staff were perhaps quieter and less willing to voice personal opinions, and overall the parliamentarians were perhaps the most open and willing to question or speculate about the 'big picture' implications. During events we also became aware that some individuals knew each other e.g. Commission officials from different DGs might know each other due to past job roles or joint-working, but we did not have perfect knowledge of these links nor their implications. The mix of individuals spanning DGs was explicitly praised by more than one participant as fostering a good "*group dynamic*" but it may also have enhanced participants' openness, as different DGs wanted to defend themselves in front of others.

Past experience – if any – with research projects and researchers also affected how participants expected to engage with us. We know from our work in phase 1 and comments in feedback interviews that e.g. it is unusual for DG Agri staff to engage with and have opportunity to shape research projects whilst they are ongoing; comments by YR in DG Agri and EG in DG DevCo suggest they are more accustomed to receiving final outputs and recommendations. This is more in line with the 'knowledge transfer' model of science-policy relationships. Our attempts to probe personal views and elicit responses to non-final outputs may thus have been unexpected, even though we believed that this was explicit in the invitations and introduction to events. The project's approach of involving policymakers throughout the project was seen as unusual and useful by some participants. However, we also received some feedback that we should have been clearer about what we expected from these engagements. "*A lesson for me is that when we implement highly policy relevant projects, it would be useful to engage and involve the relevant Commission DGs at early stages in order to have a clear idea of their expectations and to which extent the project can meet those expectations*" (AH, EASME, feedback form). Indeed, one participant, in a feedback interview, highlighted that they were unclear what was wanted from them during the seminar (EG) despite spoken, and written, entreaties to help the researchers understand the implications of the findings presented. This suggests that DG staff were not always aware of what might be of expected of them in science-policy interactions and would not be expecting the co-construction found in 'mixed teams'.

Personalities and non-public politics. All these experiences and relationships, combined with personalities, affected participants' willingness to be vocal in discussion and what topics they would comment on. For some, especially those in roles more focused on environmental issues, the problems of sustainability may have been self-evident, so perhaps stating it seemed unnecessary. For others, speculating about policy change and sustainability may have been too sensitive. There may also be sensitivities arising from other events and processes that we were unaware of, affecting sensitivities and receptivity to our method and outputs. As an example, from observing conversations at Green Week 2019 and other sources, we infer there have been internal discussions about the need for quantified SDG targets and baselines, and a specific plan for achieving the SDGs, even though publicly this has not been acknowledged by the Commission. Participants unaccustomed or unwilling to make comment - or perceiving our presentation as a unconstructive critique of their policy work – probably stayed silent, or some may even have asked questions about details of data use and presentation – e.g. claiming that recent trends were more positive than our data suggested - as a safe strategy to avoid discussing more sensitive topics.

We also received suggestions that MAGIC should work with other policy bodies but especially with the public and citizens, voiced by the Commission participants in the November 2019 workshop and KS in the JRC. The need for the Commission, media and citizens to be more supportive of radical change for sustainability was voiced by attendees at the Parliament breakfast. It is true that all sections of society must be engaged to support and enable change. However, we are also left wondering if highlighting the importance of other groups was intended to deflect attention away from a group's own agency and responsibility in achieving change. For example, some DG Agri participants suggested we should speak to DG Sante instead, since they lead on the Farm to Fork strategy, whilst some other Commission participants argued food policy was not an EU competence.

Understanding more about participants' positions, their views and their responses to our material would likely require more time, and in particular, multiple interactions with the same individual. This is partially to enable communication about the complex SMA method and its outputs, but also – at least as importantly – to foster relationships and build trust. SMA may be perceived as complex and needing more work to make it applicable: equally we as researchers are also unknown quantities, known only by having H2020 funding and whatever small amount of information we impart about ourselves at the start of meetings.

3.5.7 Emerging paradoxes in our findings

Our work was clearly seen as salient enough to some policymakers (see Section 3.5.2), to motivate them to engage with the research and attend events. We also received advice about how to make our work more policy relevant. Yet this advice on increasing policy relevance can appear at odds with stakeholders' own responses, or lack thereof, during the MAGIC science-policy events. The 'closing the loop' discussions focused on either technical questions about the SMA techniques, or terminology, or suggestions of future applications. Despite efforts, the facilitation failed to elicit meaningful discussion linking the findings about the feasibility and viability of CAP as a nexus policy supporting SDG2, despite clearly illustrating how the metrics were highlighting major challenges. These together with our own reflections, hint at apparent paradoxes, which are interlinked:

- **Engage many versus engage few.** We received advice to engage with more actors or other stakeholder groups beyond the EU institutions, to raise their awareness amongst the many other stakeholders connected with the agri-food system. This advice emphasised the distributed nature of the responsibility to achieve change for sustainability. Reasonably, every group connected with policymaking feels the limits of their own agency to achieve change. Yet at the same time, our results also push us to engage with stakeholders in a more targeted, in-depth way. This reflects the need for more in-depth engagement to build interpersonal trust and confidence, and the need for time to understand complex methods, results and implications. Whilst both responses are understandable, it would clearly be impossible with reasonably expected resources to engage with every possible relevant group and also build in-depth relationships with fewer individuals/groups.

- **Take a broad versus narrow view.** Advice to engage with more or different stakeholders can imply the need to build a broad appreciation of the sustainability issues across the agri-food systems, whereas a targeted approach with few specific actors would also tend to focus on the issues or questions they find salient, rather than presenting broad overviews of the whole system. Developing and communicating a whole system view of sustainability is in tension with focusing on a part of that whole.
- **Focus on current problems versus highlight new issues.** Some stakeholders expressed desire for more specific and targeted advice that would help inform current policy questions and processes. These stakeholders suggested that awareness of current policy context is important – and we achieved it in this work – but this is not by itself sufficient to satisfy these kinds of demands or expectations. They expected more specific policy recommendations. Other stakeholders commented that the value of new approaches such as MAGIC is to highlight issues and aspects of the system that are not currently well-considered by policymaking. Again, it would be difficult to satisfy both types of expectations.
- **Solve problems versus reflect on problems.** As the above point makes clear, some stakeholders expected MAGIC research to offer solutions or recommendations for current policy solutions, and when we did not do this then they became disappointed. However, MAGIC itself did not necessarily set out to do this. Our own aspirations were to provoke reflections on dominant narratives, in line with post-normal science. For some participants this may have occurred – see the emotional responses of some MEPs (Section 3.5.4) – but perhaps analysts were less likely to welcome or explicitly react in these terms. To influence decision framing, we may need to influence those such as MEPs who set rather than implement the policy agenda, but credibility is based on technical prowess which often requires endorsement by analysts, not politicians or publics.
- **Provoke reactions versus build relationships.** Much advice on science-policy interfaces advises building interpersonal relationships. This was mirrored by the instinctive approach and reactions of some MAGIC team members when attempting to make contacts or when reacting to questions from participants, i.e. giving emollient responses to questions, expressing interest and making enquiries about participants' own work and background. However, the QST cycle does not explicitly allow space for this to occur: the focus is on eliciting dominant narratives and then reflecting on their robustness (i.e. in terms of Feasibility, Viability and Desirability) with the normative goal of questioning the status quo.

Some of these tensions can perhaps be resolved by adjusting the QST cycle and seeing it more as a relational process. However, other tensions, such as the advice to engage more widely and more in-depth with specific actors, cannot easily be resolved. These tensions suggest QST is not easily implemented to satisfy all expectations and interpretations.

4 Reflections and next steps

The QST process is designed to be a quality check on the process of generating and using knowledge, and in this application the knowledge pertains to policymaking and ex-post policy evaluation. Our application of QST asks whether the current institutional arrangements for delivering SDG2, particularly target 2.4, are appropriate, or whether change is required. The reflections consider the findings from both the semantic and formal parts of the QST cycle and discusses their implications in the context of the current EU sustainability and sustainable agriculture policy. The first section (Section 4.1) covers the insights generated on the domestic EU agricultural system. The second section (Section 4.2) covers the issues of policy coherence. The third section (Section 4.3) discusses how a SDG framing implies the need to reconsider the ideas of policy coherence, to include the externalised impacts of domestic EU food production. The fourth section (Section 4.4) considers what has been learnt from the application of QST with EU policy mixed teams, with the final section (Section 4.5) section synthesising areas for further research.

4.1 Sustainable agriculture: Is the status quo desirable?

The SMA metrics (Section 3.4) discuss feasibility in terms of the pressures on the biosphere; and viability in terms of pressures on the technosphere, both in terms of within-EU agricultural production systems and their draw on systems beyond the EU borders. The results presented in Section 3.4.1.2 confirm that agriculture is the predominant land use in the EU, a reminder of why a focus on EU agriculture is important despite its relatively small economic contribution to the EU economy. This section focusses mainly on sustainability within EU borders, with the importance of considering openness and externalisation highlighted in Section 4.3.

4.1.1 Environmental pressures and feasibility

The environmental pressures, particularly where illustrated using relationship mapping in Section 3.4.2.3, start to show where there is intensive agriculture (higher rates of use of inputs such as fertiliser, crop protection products and imported feed). These intensive systems are relatively widespread, implying greater potential impacts e.g. on water quality and biodiversity.

Although analysis takes a pan-EU approach, it is not only broad-brush. Figure 36 - Figure 38 are also good examples of the intensive nature of small island agriculture in the Mediterranean and Caribbean, where pressures on water and biodiversity cannot be mitigated by downstream dilution or biological refugia from an adjacent region. Figure 40 is another illustration where extents alone would obscure the few examples whereby there are small but intensive livestock systems utilising smaller land areas and heavily reliant on imported feedstuffs.

Sections 3.4.2.4 to 3.4.2.7 clearly illustrate that there are widespread impacts on pollinators, soil, water quality and water quantity (flow) occurring in areas where agriculture is the major land use. The results illustrate, for example, the importance of soil as a lens onto the WEFE nexus (Blackstock 2020). The links between soil and land use is something the European Environment Agency (2020) have highlighted as a gap. In particular, the SMA approach is helpful in illustrating that unsustainable water use is not only a southern EU problem, given that many northern and western FADN regions are using green water at an unsustainable rate (Figure 44).

4.1.2 Socio-economic pressures and viability

In terms of viability, there are also questions about to what extent the agricultural sector provides meaningful, year-round and well-paid employment (Section 3.4.1.3), and provides a reasonable standard of living (Section 3.4.3.1). CAP is associated with agricultural employment in some Member States e.g. France, Spain and Italy but not all (Section 3.4.1.7), with many of the other Member States relying on family labour (Section 3.4.1.3). Many countries in the north and west of the EU are receiving support for agricultural employment when there are many other economic opportunities (Section 3.4.1.6) available to rural labour. The conflict between agricultural and other sectors in terms of competition for labour has been linked to potential questions about the extent and distribution of land abandonment (Section 4.5.3). However, in areas where there is potential for diversification into other rural development opportunities, this may suggest that 'land sparing' for conservation and climate outcomes might be more possible. This latter proposition also concurs with finding that many of these areas are also subject to relatively high capitalisation rates (Section 3.4.1.4).

CAP subsidies can also be problematic when subsidies become incorporated into the capital value of land, since increasing land prices can attract speculative purchase of land as an investment[17],meaning that ownership or even use access can become a barrier to new entrants. Lack of turnover of land ownership stifles innovation within agricultural production systems with potentially negative consequences. This is a counter narrative to the policy documents (European Commission 2019d; European Environment Agency 2020) that promote use of private finance to achieve sustainability, when existing financial markets are responsible for skewed land values that make some CAP objectives more problematic to achieve (Kilian et al. 2012; Thorsøe et al. 2019).

The SMA analysis, complex as it is, raises questions about the narrative of CAP generating viable food production systems and balanced territorial development. Section 3.4.3 illustrates how many farm types in many regions would not be viable without CAP payments. Overall, although CAP spend has been justified by multi-functionality (not only economic benefits but also the environmental and social pillars of sustainability), the reality is that continues to fund higher output farming systems that generates higher pressures on environment (and energy) with limited social or economic justification. The metrics also suggest that EU farms tend to be specialised, and that there is a lack of mixing between crops and livestock production systems. Potentially CAP subsidies help farmers to maximise profitability, building on local comparative advantage, and specialise in the most economically viable activities. This, however, reduces land use and land cover diversity in these regions.

The analysis by farm type and FADN region ensures that the viability stories remain nuanced. For example, there are differences in how diverse the mix of farm types are within Member States (Section 3.4.1.1 and 3.4.1.5). Most Member States have some form of milk and granivore production; red meat and cereals production is more distributed than cropping; and cropping systems are more diverse in the south and east of the EU. Such findings are important in terms of system resilience to economic shocks but also to pests and diseases, or climate related hazards.

4.1.3 Sustainability: geographical themes

The characterisation of structure and environmental pressures in the SMA adds to the existing evaluations of EU agriculture and the evaluation of CAP (European Court of Auditors 2020). Our critique of the CAP and need for WEF nexus thinking is not new and has been well-covered by others. However, whilst many others have pointed out individual aspects of these results, this report offers a new contribution by simultaneous consideration of multiple dimensions in terms of social, economic

[17] Since land is finite and to data has had limited availability, investment in such assets can generate short term returns regardless of use value fostering speculative or even Ponzi scheme behaviours with little societal benefit.

and environmental issues; and doing this across multiple analytical scales, both geographical and sectoral. What the MAGIC SMA adds is increased granularity by farm type and FADN region, whilst retaining an overall pan-EU perspective. MAGIC draws attention to the need to jointly consider land cover (for environmental impacts on habitats), land uses (which are supported by CAP funding instruments), and land management (though this is harder to quantify using FADN data)[18]. Our SMA also draws attention to the cumulative pressures that may still result even when 'good practice' management is followed by individual farmers. Therefore, the analyses suggest that overall, albeit with some exceptions, EU agriculture is not sustainable in terms of its draw on the biosphere and it is questionable to what extent it is viable in terms of its use of funds and flows in the technosphere.

The SMA illustrates the challenges of WEFE nexus European-level policymaking arising from heterogeneity within and between Member States and FADN regions. The chord diagrams and relationship maps illustrate the complex nature of how the funds and flows are distributed between farm types and FADN regions. With the varying combinations of production systems, environments and pressures tailored measures will be required. The SMA also shows the need to have a pan-EU overview of this heterogeneity to observe where policy objectives are not being met. Therefore, it is important to pay attention to multi-level governance processes, and this explains why EU policies are often 'framework' in nature, allowing flexibility in implementation by Member States. This relies on Member States or regions taking the opportunities provided in EU regulations, but also in being ambitious which is challenging against a background of austerity in the wake of the 2008 financial crisis, and the 2020 pandemic. A resulting question is what is the appropriate role for supra-national institutions such as the EU? The answer informed by the QST and SMA would be in framing the issues, collectively agreeing the standards that need to be met for environmental sustainability, and ensuring a level playing field such that no region or Member State can free-ride on the back of efforts by others.

There are some pan-EU themes visible such as the recurring motif of specialist COP having the largest extent for any farm type in the EU (Section 3.4.1.2) and being the farm type with the most support from CAP payments (Section 3.4.1.7) and reliance on these payments for economic viability (Section 3.4.3.1). The extent of these payments could be seen as surprising as the sector has limited uptake of environmental payments (beyond greening measures counted as part of decoupled payments), provides limited employment (Section3.4.1.3) and generates relatively modest Farm Net Incomes (Section 3.4.3.1) and is a substantial exporter (Section 3.4.4.2). Specialist cereal production is responsible for pressures from fertiliser use and crop protection products (Section 3.4.2.1). However, the cross-scale dimension is important here, as if these commodities were not supported in the EU, they would potentially be imported from agricultural production systems that may have worse environmental and social pressures. In contrast, some farm types like specialist olives, wine and horticulture, use relatively little land but are relatively intense users of agricultural labour (Section 3.4.1.3) and have relatively strong Farm Net Incomes (Section 3.4.3.1) despite minimal CAP spend. Despite their relatively low CAP support these farm types seem to be supporting many of the future CAP objectives (fair income, vibrant rural areas, protect food quality).

Livestock farm types, producing red meat, appear to receive most of the CAP environmental payments (Section 3.4.1.7); and whilst specialist milk systems have the largest Farm Net Income (despite the volatility of milk prices and market access over the 2014-17 period) specialist livestock systems seem particularly reliant on CAP payments to remain in business (3.4.3.1). Furthermore, when embodied green and blue water is calculated (Sections 3.4.2.1 and 3.4.4.1), livestock production systems seem

[18] Land use refers to the overall function for the land (e.g. which crop or type of livestock production) and land management refers to how these uses are implemented e.g. whether the cropping is no-tillage, or the fields have buffer strips etc.

likely to have significant negative impacts on water and biodiversity and are significant emitters of greenhouse gasses. These impacts may even increase if feed inputs must be provided domestically due to changes in the trade context. Given the proposed regulatory agenda under the Farm to Fork Strategy, such as restricting imports of commodities that use banned crop protection products, the reliance on such imports may become more problematic. The impact analysis also suggests in some cases e.g. Figure 41, extensive systems are not always positive for pollinator biodiversity.

4.1.4 Implications for farm data

The results also highlighted some important lessons for adapting the FADN database. The analyses in Section 3.4 identified areas where moves to present data in terms of material quantities (tonnes, types) as well or instead of financial values (euros) will help the proposed shift from Farm Accountancy Data Network to Farm Sustainability Data Network (as highlighted in the Farm to Fork Strategy). Examples of where this would be helpful include: the need to collect the type and tonnage of different crop protection products (Section 3.4.2.1); and the power capacity and embodied energy in machinery and buildings (Section 3.4.1.4). Providing this information in both kW and monetary terms would allow the energy (and climate) implications of different farm types and regions to be compared more effectively. Another area of potential improvement for FADN might be to capture more information about the materiality of inputs. For example, distinguishing different types of crop protection products in terms of their types and ecotoxicity, not just in terms of their monetary costs, would allow a more explicit analysis of potential impacts on pollinators by farm type and region. The attribution of capital and labour within farm types also needs attention to ensure that these are net not gross values. Capital inputs need to be considered in material terms, including embodied energy over their lifecycle, potentially using Farm Structure Survey data.

The importance of off-farm funds (e.g. contractor machinery and labour) is also important and potentially underestimated in the current SMA and needs attention in terms of data collection and analysis. The SMA approach working up from the detail in production step analysis, via sequential pathways to production systems, can help fill gaps, but potentially it might also be possible to work at the production system level using benchmarks. Overall, an integration of economic and biophysical data would help further analysis of the complex interactions between intensity and extent measures across farm types, supply types and geographic levels. These approaches help move the analysis from weak sustainability (believing that human-made capital can substitute for natural capital) to strong sustainability perspective (Dietz and Neumayer 2007), whereby the biosphere fund must be utilised within planetary limits.

4.2 Policy coherence – CAP as a nexus policy

This section addresses to what extent the SMA metrics suggest CAP has been able to address all aspects of the WEFE nexus and their associated policy domains, as well as wider issues of policy coherence.

4.2.1 The degree and nature of change to meet 2014-2020 CAP objectives

The findings in Section 3.4 suggest that the 2014-2020 CAP objectives were not fully met. The CAP may be necessary, quoting: Alliance Environnement (2019a: p162), *“The presence of the CAP has raised Member States’ ambition, resulted in higher financial allocations and increased the effectiveness of biodiversity, habitat and landscape action at EU scale than would be the case with purely national measures”*. However, at present CAP does not adequately respond to EU sustainability issues. This is partly about implementation: the European Court of Auditors (2020) states that direct payments are 70% of EU agricultural spending but effects on farmland biodiversity is limited; whereas the rural development instruments have more potential but are used less often. The response from the Commission (European Commission 2020c) notes that they provide legislative minimum standards and incentives via a wide range of agri-environment options, but it is up to the Member States to take up these options at ‘sufficient scale’: this response highlights the responsibility of Member States. Given that the post-2020 CAP objectives are more expansive and ambitious, the analysis suggests a considerable change is required. Despite the relative positive impact assessment for the post-2020 CAP (European Commission 2018b), the relatively minor tweaks in CAP instruments and CAP spend that were recently proposed by the new Commission (European Commission 2020b) do not suggest to the authors that a sufficiently ambitious change is being considered at present.

4.2.2 The degree and nature of change to meet WFD

Section 3.4.1.4 suggests that dairy has the most intensive levels of capital investment in terms of machinery and buildings. This may be partly related to the implementation of cross-compliance measures to ensure that nitrates from farm manures and slurry do not pollute surface or groundwaters within Nitrate Vulnerable Zones (with the Nitrates Directive being a daughter directive of the WFD). However, the findings in Section 3.4, particularly Section 3.4.2.6 and Section 3.4.2.7 suggest that agriculture still has a major role in causing impacts on the status of water bodies, in particular the need to pay attention to embodied and actual draw on green water. The EEA (European Environment Agency 2020) believe that emissions to air and water have been reduced, and water abstraction reduced by 19% from 1990-2015, concluding the main impact from agriculture is to biodiversity and habitats. However, Alliance Environnement (2019b) found that Member States generally settled for minimum standards in their design and implementation of cross compliance and Rural Development Programme measures, with very few directly targeting water quality and quantity issues, so the impacts of CAP are indirect and diffuse. This analysis also found conflicts identified regarding impacts on water resources, amplified by the fact that many sectors with impacts (flowers, fruit, wine) are not covered by direct payments or Good Agricultural and Environmental Conditions. These weak policy levers within CAP might explain the fact that despite reduction in intensity of use, there was no reduction in pressure on water resources within Spain or the Netherlands detected during the first river basin management planning cycle (Krol 2019). The expectation that CAP enables delivery of good status is therefore questionable, and tension between restoration objectives and rural economic development based on agro-food systems, remains.

4.2.3 The degree and nature of change to meet EU 2030 Biodiversity Strategy

The SMA considered pressures and impacts on pollinators, which are an important indicator for biodiversity, but not directly an analysis of whether we will meet the objectives of the Natura 2000 directives, since these are presented in terms of ‘favourable conditions’ of habitats and sites. However, the overall pressures (Section 3.4.2) might suggest that agriculture does not necessarily support good condition for fragile habitats and their species. Alliance Environnement (2019b) agree with European Court of Auditors (2020) that CAP measures have not been able to counteract pressures on biodiversity from agriculture. Pollinator results show that northern Europe’s increased use of crop protection products (Section 3.4.2.1), is associated with lower pollinator index results (Section 3.4.2.4), confirmed in Figure 41. These results concur with Eurostat’s reporting that one of the SDI’s for SDG 2 (farmland butterfly index) was responsible for slow progress to SDG2 (Eurostat 2019). CAP has not been effective to date as a nexus policy in this domain given that Alliance Environnement (2019b) found uptake of specific agri-environment measures were too low and Member State implementation missed opportunities to use wider instruments to help redress pollinator decline. These findings suggest that the objective of no net biodiversity loss remains difficult to achieve.

4.2.4 Energy Efficiency Directive and Circular Economy objectives

The analysis presented in Section 3.4 did not consider GHG emissions, renewable energy use or energy efficiency, due to limitations within the FADN data sets. The energy data within FADN are expressed in terms of Euros and while there some detail in terms of motor fuels and heat, for an energy analysis to be effective the nature of the energy carriers used needs to be explicit and represented in physical terms (Giampietro et al. 2014). The analysis presented in Section 3.4 did not consider reuse and waste within the on-farm agricultural production systems. These are addressed under further research (Section 4.5.1).

4.2.5 Overall policy coherence – with greater ambitions

The EEA (European Environment Agency 2020) suggests that there is a need to strengthen CAP policy implementation and ensure policy coherence. Combining insights from Section 3.2 and Section 3.5, it is possible to see that the Commission has positive aspirations to have coherence across multiple policy domains. However, it appears that coherence is to be achieved using standard business-as-usual policy instruments (economic incentives, voluntary behaviour based on information, backstop of general regulations and a belief in efficiency as a solution though technical innovation). These will be used within the existing policy implementation process where the EU provide a framework and the Member States tailor these to their context, providing opportunities for a lack of ambition. This could suggest issues of both institutional inertia and a tendency to focus at the lower levels of the agri-food system (Figure 55) such as production steps, and production pathways but not addressing issues with supply systems or societal demand.

The Commission continue to defend their approach to increasing policy coherence in the WEFE nexus domain. For example their response to the European Court of Auditors' critique (European Court of Auditors 2020) of CAP failing to halt the decline in farmland biodiversity was to assert that their policies were suitably coordinated (European Commission 2020c). Whilst there were limited examples of explicit incoherence found between CAP and biodiversity policy design, there was potential for ineffective implementation, due to differences in design at Member State level (Alliance Environnement 2019a). The same report also concluded there were opportunities for greater synergy and contribution to delivery of EU Biodiversity Strategy, including Natura 2000. Again, Pillar 2 measures (particularly Agri-Environment Climate Measures and organic farming measures) are identified as the best way to address pressures on biodiversity within farmed areas. However, Pillar 2 measures could be complemented by broad-but-shallow approaches in Pillar 1, making payments conditional on delivering environmental outcomes (i.e. improving on rather than abandoning the ecological focus areas in CAP Greening). To be effective such measures need to be better targeted and monitored and land managers need greater supported in implementing them. Otherwise these approaches are unlikely to deliver the scale and pace of change that the SMA metrics might suggest is needed.

The proposed EU recovery plan (European Commission 2020a: p6) positions the proposed European Green Deal as a 'job-creating engine', primarily through investment in circular economy, clean industry and value chains. This suggests the need, anticipated in the Farm to Fork Strategy (European Commission 2020d), to address sustainable agriculture beyond the farm-gate but to understand how on-farm social and environmental pressures are influenced both by the CAP and the wider supply chains and trade relationships within the global food system. This problem-framing reinforces the importance of using an SMA based on a systemic characterisation of the funds and flows associated with the metabolism of food in EU (supply systems and final consumption) to provide a deeper understanding of the existing situation and to what extent there could be more 'circularity' within the existing metabolic pattern. Delivering such an analysis will mean the need to resolve the silences and gaps apparent within our institutional and policy analysis regarding the lack of explicit interactions of energy policies with agriculture; and suggests the need for an explicit energy indicator within EUROSTAT's SDI set. Furthermore, it adds further weight to the need for FADN and other relevant agricultural data sets to improve their data on energy carriers and associated flows for EU farming systems.

The EU recovery plan also highlights the importance of protecting and restoring natural capital, including meeting the EU Biodiversity Strategy 2030 objectives through leveraging €10billion via the InvestEU initiative. The Green Deal Recovery plan will increase the budget for the European Agricultural Fund for Rural Development by £15 billion, which will begin to help redress the existing imbalance between spend on production systems and more targeted measures (Pe'er et al., 2019 Science). For CAP to achieve sufficient biodiversity improvements, it requires *"sufficient levels and security of funding at programme level (including from sources outside the CAP) to deliver the scale and quality of implementation required to achieve specific biodiversity objectives in the long-term; and at scheme level, funding allocations to secure the 'critical mass' of uptake needed, and payment rates and eligibility set at levels that encourage high-quality biodiversity management*." (Alliance Environnement 2019a).

The language of a green transition again suggests that there is a recognition that change is needed and the ambition to deliver change is present. However, the proposals of how to use CAP to support the Green Deal (European Commission 2020b) suggest an incremental approach of reliance on Member States to implement a menu of 'green architecture' rather than the radical adjustment that our interpretation of our data might suggest. Much will depend on the detail of the green architecture, the allocated funding to the different instruments, and the ability to monitor progress. The efficacy of CAP instruments, imbalanced funding allocations and opaqueness of progress has been criticised in the current period, including by the EU's own institutions (European Court of Auditors 2020).

Taking a PNS perspective has been challenging when also trying to engage with the metrics generated by the SMA, given that PNS requires the analysis to question the 'taken-for-granted' framings. Therefore, not only do the metrics question the claims to environmental, social and economic sustainability of the EU agricultural system but a full PNS analysis requires a wider consideration of how these claims are generated and in whose interests. These ideas are implicit in the above discussion but are developed further in Sections 4.3 and 4.4 below.

Meeting the desire for a WEFE nexus coherent CAP to deliver SDG target 2.4 (sustainable agriculture) is not just about sustainable intensification at the individual production step level but means the need to critically reflect on where policymakers could intervene. This wider analysis starts to raise provocative questions such as would CAP payments be better spent in targeting food insecurity (within EU as well as beyond) at the consumption level? These ideas are implicit in the above discussion but are developed further in Sections 4.3 and 4.4 below.

4.3 Lessons learnt about SDG2 and the UN 2030 Agenda

SDGS are more ambitious and more synergistic than MDGs; and apply to all signatories including the global North. Section 4.1 above begins to address aspect of the SDG's meta narratives: 1) leave no one behind; 2) ensure equity and dignity for all; 3) achieve prosperity within Earth's safe and restored operating space, but this section brings out the international dimension. Firstly, other authors (Koff 2017; Lorenzo 2017) have observed that the UN 2030 meta narrative co-exists with a geo-political context that is becoming more divisive, more unequal and is increasing its demands on the biosphere. They also observe that the SDGs are still not a coherent or systemic approach to sustainable development and tend towards a weak interpretation of sustainability. Others have suggested that on current trajectories, the EU will not achieve the goals by 2030 (SDSN & IEEP 2019). This is unsurprising given that the previous sustainability goals in the EU Sustainable Development Strategy also were not fully achieved (Union 2006). Renda (2017) has also questioned the methodologies used to address policy evaluation for SDGs, suggesting that current approaches focus more on efficiency than on sustainable development. Increased attention to policy coherence with EU regulatory governance, to improve the mainstreaming of the SDGs, is needed (Renda 2017).

4.3.1 SDG2 Beyond the farm gate

Within the domain of agriculture, the dominant response of promoting sustainable intensification on the lowlands and extensification in the uplands still puts unfeasible pressure on the biosphere and needs reconsidering. Given the issues of 'openness' it is important to consider this systemically, not just within the agricultural system but across the whole agri-food system, connecting production and consumption. That this has not been undertaken could suggest that there are issues of institutional inertia and a tendency to use a 'simpler' issue framing that focuses on technical fixes in production steps, and production pathways but not on addressing issues with supply systems or societal demand.

The UN2030 agenda has encouraged refocusing the attentions of EU institutions from agriculture on farms to agricultural value chains, the role of supply chain actors and consumers. This makes a SMA even more salient as the authors suspect that for some indicators such as materials and energy use there may be even more pressure exerted on the biosphere in the supply chain (in developed countries, up to 80% of the energy used in the food system occurs in post-harvest processing and food processing (Heller 2000)), raising questions of long term Feasibility. There are also questions about Viability and Desirability given the low pay and gendered nature of food processing jobs; and questions about why the creation of agricultural commodity flows are relatively poorly rewarded. There are questions about the appropriate role of public policy levers too, given that supply chains respond to market signals and consumer preferences as much as policy. This generates issues of legitimacy and authority for EU institutions (Gölgeci, Murphy, and Johnston 2018), as supply chains are often controlled by multi-nationals and the WTO agenda. There is potential to dilute the role of EU institutions e.g. the domestic DGs, notwithstanding the DG Agri ambition to use post 2020 CAP to 'rebalance power in the food chain'.

The findings emphasise the importance of looking beyond economic value to material funds and flows within the EU for any analysis of food security (Section 3.4.1.1) while recognising that overall food security is a result of how the EU food supply systems function in a globalised world (Section 3.4.4.2). Much of the attention to the international dimension has focused on trade and food (in)security and nutrition in the global South. The findings in Section 3.4.4 illustrate the importance of considering the interconnection between the international dimension and the implementation of domestic policies e.g. CAP within the EU territories. The reinternalisation analysis (Section 3.4.4.3) clearly illustrates how the 'footprint' of EU agricultural systems extends beyond the EU territorial boundaries in terms of both embodied land and labour. Figure 50 illustrates the EU's reliance on imported livestock feed from North and South America. This reliance can be criticised in terms of contradicting the EU's commitment not only to sustainable agriculture (SDG2) but also achieving global decreases in GHG emissions (SDG13) and no net loss of biodiversity (SDG15) given the criticism of the climate and conservation impacts of farming practices used to produce feedstock in these countries (Sauer 2018).

4.3.2 Measuring sustainability in a globalised world

This connection between international trade and EU agri-food systems implies two measures of performance that can only be considered at the level of supply systems: openness (the share of resources used in a system) and externalisation (the reduction in pressure on local funds). The former has implications for food security since assumptions of only moderate scarcity of resources may not apply in the medium term. The latter has strong implications for how any assessment of EU environmental sustainability is assessed since any current accounting e.g. of GHG emissions or soil/biodiversity loss for the EU ignores the footprint of imports. This is an incentive to achieve greater apparent sustainability simply by reducing local intensity of production with any deficit in societal demand being made up by imports. These issues cut across the objectives of SDG2 both within the EU and in trade partners and imply complex policy trade-offs and governance challenges. Yet for exports the environmental footprint is internalised in any assessment of the sustainability of EU agricultural production systems so there is trade-off between environmental and food security objectives for the EU in delivering SDG2 ambitions.

The Farm to Fork section (European Commission 2020d) on 'Promoting the Global Transition' is focused on using EU external cooperation and trade policies to cooperate with other partners to build sustainable food systems through trade agreements focused on animal welfare, pesticides and anti-microbial resistance. Although the document notes prospective legislation in 2021 aimed to avoid importing products directly associated with deforestation, there is no reference to the fact that through embodied water, soil and nutrients, the inputs to EU agricultural and associated food value chains, put pressure on agro-ecosystems around the world. There are no specific actions regarding these externalisation issues (see Section 3.4.4) in the list of actions in the Farm to Fork Strategy. This should be addressed. As recently as May 2020 (European Commission 2020b), the Commission presented a SWOT analysis as the ex-ante evaluation methodology for implementation of the future CAP via Member States' CAP Strategic Plans. This process, to our view, is inadequate for a full systemic understanding of the agro-food system, including the dependencies and spill-over effects with the EU bloc and beyond.

The EEA's most recent state of the environment agrees with the analysis presented in this report. The EEA recommends that policymakers acknowledge the sustainability challenges that require urgent systemic solutions (European Environment Agency 2020). Their analysis of 'sustainability through a systems lens', suggests the need for more understanding of the consequences of EU's trade, and analysing interconnections consumption and production links. As the EEA (2020) notes, the message that our current production and consumption systems are unsustainable is not new, but the EU is still transforming its thinking about sustainability rather than taking action. What is new, in the view of the EEA, is the social dimension and the need to have a just transition and pay attention to the unequal distribution of costs and benefits (see Section 4.5.2 for future research questions).

Responding to the SDGs has refocused attention on policy coherence, both policy coherence for development (externally to the EU) and policy coherence within the EU. Therefore, policy coherence is needed, but not just about coherence between environmental and socio-economic agricultural policies but much more complex horizontal coherence between a much wider suite of policy domains. Furthermore, more focus is needed on effective vertical coherence between the espoused objectives and normative narratives surrounding them; and the policy instruments and their implementation, where there may be a considerable disjunct. This is relevant given the dominant meta-narrative of the Green Deal in the new EU institutional arrangements.

4.3.3 SDG2 and links to other SDGs

Therefore, whilst the primary focus is on SDG2, it is also important to consider how aspects of SDG2 link across the five EU policy domains, to other SDGs (explicitly and implicitly). SDG6 target 6.6 (restore water-related ecosystems) and SDG 15 target 15.5 (halt biodiversity loss) were both to be achieved by 2020. Results presented in Sections 3.4.2 suggest that this will not have been achieved (see also (Alliance Environnement 2019a, 2019b; European Court of Auditors 2020). This suggests that the degree and speed of change required is more radical than currently proposed, not only to meet the proposed policy narratives associated with the new CAP, but also to achieve the synergies with other

SDGs, as highlighted by the Commission themselves. Even taking such a partial view of one SDG suggests a less optimistic view about achieving coherence and synergies than that suggested by the CAP impact assessment (European Commission 2018b) or the policy coherence report (Miola et al. 2019).

In terms of further research, there are other linkages that could be pursued (Section 4.5). The highlighting of the importance of family farming (Section 3.4.1.3) draws attention to potential issues with opportunities skewed by gender and age. These are issues that post-2020 CAP objectives seek to address (support generational renewal), and of relevance to SDG5, particularly action 5a (Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance, and natural resources in accordance with national laws). The recognition of value chains also draws attention to SDG12 (sustainable consumption and production). As Section 4.3.2 illustrates, it is important to understand the global aspects of domestic food production in order to truly have a sustainable approach to food security.

4.3.4 Aspects of SDG2 not covered by the QST

The findings in Section 3.4.4.2 show the role that the EU plays in terms of food supply in areas such as the Middle East and Africa. However, this QST cycle did not address some aspects of SDG2 (see lower left quarter in Figure 3) relating to hunger and nutrition within the EU. EU policy actors argues that the EU plays a limited role in food and nutrition (Section 3.5.5), as this is the jurisdiction of Member States. Understanding this institutional tension between the EU and the Member States is important for contextualising how the QST results might have been interpreted. Furthermore, our experience in opening and closing the QST cycle suggest that the SDGs are a steering policy that EU institutional actors 'link to' but few have had a direct mandate to deliver in the period of the QST cycle implementation. As noted in Section 3.2, the QST cycle was implemented during a period of transition, or tension, between servicing the 'old' agenda of the Juncker Commission whilst making space for the 'new' UN2030 agenda that wasn't really given full voice until the start of the von der Leyen Commission. This provides a useful context to consider lessons learnt from the implementation of the QST cycle in Section 4.4 below.

4.4 Lessons learnt about undertaking QST

As introduced in Section 1.2, QST is more than a participatory approach to societal metabolism accounting, but an integrated approach to post-normal science. The 'semantic' aspects of QST (the engagement with stakeholders, identification and articulation of dominant framings) are used to inform the 'formal' aspects of QST (the quantitative societal metabolism accounting) with the intention that the formal-analytic outcomes are considered salient and credible (Giampietro, Allen, and Mayumi 2006). QST questions whether existing science-policy arrangements ignore existing risks and threats because they take too narrow a view of the challenges faced by the EU. Potentially, QST processes could help those engaged to reflect on the problems of policy inertia, recognise the importance of articulating hidden conflicts, or to reflect on the processes shaping evidence use. This section addresses the degree to which these ambitions were met, and the lessons learned for the future use of QST.

4.4.1 Timing and salience

Undertaking QST in diagnostic mode requires moving back and forward between 1) what we knew and had learnt from our stakeholders when we were starting the QST cycle in early 2019 and 2) what was salient to when presenting later in 2019 and early 2020 – as there were many changes over that period. The quantitative data being presented also reflected the outcomes of previous policy decisions. This creates temporal complexities of making the MAGIC results relevant to future policymaking, whilst contextualising the results in past policy choices. The institutions and their actors evolve and change, so implementing QST is always being done during flux.

The context for the SDG2 QST was the change of Parliament, Council and Commission; and the transition from the EU 2020 Agenda and its supporting 7th Environmental Action Programme to new Agenda and 8th EAP. For example, Green Week 2019 was all about taking stock, adding in the UN SDG agenda and identifying the “future EU environment policy post-2020”. During 2018-2019, when the foundations for the EC Reflections paper and the post-2020 Strategy were being laid, the Vice-Presidents were in campaigning mode (JR Advocacy NGO) which the interviewee suggested meant Vice President Timmerman (in charge of Sustainable Development within the old Commission) “*is a little bit more bold I think. So he is more into sustainability as such and is more and more sticking out his neck*". Thus, the QST potentially aligned with a policy window (Rose et al. 2017), as the approach was extremely appropriate to address these wider narratives of the EU as world leaders in development policy, as well as delivering a competitive green economy with equitable outcomes for all. Ironically, whilst this made findings more salient, those we wanted to engage were extremely busy responding to the flux, even before the Covid-19 epidemic.

4.4.2 Stakeholder engagement

Engaging stakeholders, particularly ‘elite’ actors, can be challenging (Smith 2006) and it was ambitious to focus on actors within the Commission rather than engaging at a Member State, regional or local level. This is partly about time constraints, but most stakeholders face these issues, but also about roles and responsibilities. If MAGIC is perceived to appraise the sustainability of societal systems but not the effects of policies themselves e.g. analysing the sustainability of agricultural systems but not analysing the effects of CAP, this limited its salience to those who design specific policy. It explains why the approach was more favourably evaluated by non-Commission actors (e.g. EEA or the advocacy NGO) who are not directly responsible for policy implementation.

The QST process of engaging with policy actors is implicitly about procedural justice. QST considers to what extent the policy decision-making process is deemed to be legitimate in terms of participation in the process, the ability to express opinions freely and to be heard (voice), being treated with respect, having adequate information, and making ‘‘*decisions that are responsive to information and that are correctable in the face of new information*’’ (Maguire 2003). This is important because many Commission staff implement policy using set institutional processes that determined how they are expected to respond to new information. These are processes that they may not be involved in defining nor feel able to influence.

Despite much effort, it proved very difficult to identify, let alone engage, the ‘right’ actor at the ‘right’ time. How to identify and gain access to a policy entrepreneur (Timmermans, van der Heiden, and Born 2014), willing to disrupt the status quo, rather than a stereotypical bureaucrat wishing to advance policy incrementally and within the existing arrangements, remains a challenge.

4.4.3 Semantic choices

Reflecting on the semantic processes, Section 3.5 suggests that to a point, a range of relevant actors were engaged in closing the QST loop and some individuals found the process thought-provoking and potentially useful to helping with the proposed transformations under the Green Deal. It proved difficult to follow conventional science-policy good practice of presenting the policy relevant messages from the case first, before explaining the approach. The novel nature of both the societal metabolism analysis, and the post-normal science approach meant that the results were hard to interpret without some baseline understanding of the central concepts. The presentations also focused on explaining why a new approach was needed and illustrating its innovation to be scientifically credible, meaning there was less time available in a short seminar to explore the salience of the results with stakeholders.

The feedback encouraged QST to focus on existing ex-ante or ex-post policy evaluation criteria and processes to show how there are gaps and the need for an approach to complement them or go further. This was done as part of QST (see Section 3.2 and 4.1) but it remained implicit in the presentations that were dominated by providing an overview of how SMA illustrates the fundamental sustainability challenges across geographic scales and farm types. A more explicit focus on policy processes in use might have better facilitated discussion and debate by contextualising material in terms of pre-existing institutional arrangements. However, this runs the risk of constraining thinking to the existing institutional arrangements, critiqued for generating 'socially constructed ignorance' (Rayner 2012) by reducing the problem to only those parts amenable to standard economic or other conventional modelling analyses that are more readily appropriate for existing policy instruments. Indeed, some responses to the presentation of EU agricultural systems as unsustainable tended to claim either that progress, albeit slow, was being made or to advice to focus on a technical aspect of the methodology rather than engage with the full scale and extent of the sustainability challenge (Section 3.5.4). This could be read as deflection and the defence of the status quo, whereas PNS requires in stakeholders a willingness to explore transformation. However, even those supportive of the QST approach suggested that there be more focus on the 'good narrative' and how insights complement existing efforts rather than critiquing these efforts. Therefore, perhaps the PNS approach, that tends to reframe and question the status quo, generates a tension when trying to be credible, salient and legitimate (Cash et al. 2002).

4.4.4 Climbing the impact ladder – achieving conceptual change

The feedback interview process was extremely useful in revealing interest and conceptual impact that was difficult to assess during the face-to-face interactions. Indeed, consistently through the project it felt to the scientists that the pan-EU, broad-brush focus on problem-framing and highlighting the suite of pressures was not salient to individuals, yet the feedback showed that some individuals were interested and were disappointed that there was not further engagement with them. This highlights the need to devote resources to keeping in touch with mobile and extremely busy EU officials to ensure salience is sustained and built on over the lifetime of the research such that it maximises the potential for impacts such as conceptual change. The QST process, with the focus on reflexivity and questioning the status quo without claiming to provide solutions, was extremely unusual for most of our participants, and it would be useful to find ways to make clearer that QST aims to provoke reflection and does not to offer simple technical solutions, to manage expectations.

However, it may also be important that a QST implementation does not try to provoke mindset change the first time, but rather to use group events to find champions (notwithstanding the point about champions not being easily visible) and then to focus on these champions and their needs before returning to group engagement armed with results that connect with specific policy problems and that demonstrate credibility and thus the legitimacy to ask bigger questions. This may require potentially conforming more with existing expectations and norms to build relationships and demonstrate salience and credibility, and then only later moving more to provocation. The cross-DG approach was appreciated, although it created challenges for open reflection and critique of the status quo. The sequence of group-individual-group interactions would also help with this aspect. Multiple iterations with a champion was the original intention, but it was difficult to find a champion and a topic to enable this (see comments in Section 2.2 on the choices made). Delays in accessing the FADN data and completing the new version of the MuSIASEM processor prevented conducting further QST iterations within the time frame of the project. Further iterations, with the same individuals if job mobility within the Commission allowed, would help overcome the point about needing familiarity with concepts to fully engage with QST.

Overall, it is important to recognise the semantic phases as challenging and important and to be sure to devote appropriate time and resources. Indeed, it would be useful to revisit the QST cycle to see how different aspects of the credibility, salience and legitimacy concepts (Cash, Clark et al. 2002) are fostered by, or in tension with, different QST stages. An important lesson was that the QST cycle can be usefully back-engineered by starting with the potential 'end-users' and desired impacts in stage 5 and then considering what is salient to present, working backwards around the QST cycle. This process revealed that the conduct of QST is potentially more complex and iterative than presented in Figure 3, involving many micro decisions as well as revealing some element of path dependency as the data and accounting formalities condition what stories can be told.

4.4.5 The challenges of implementing an SMA

Moving to learning about the formal stages of QST, there were many challenges here, not least for a team trying to apply MuSIASEM for the first time using a complex but partial data set (FADN). It remains a challenge to link data on the management practices of agricultural production systems to environmental outcomes since the since FADN data becomes progressively less representative and reliable as smaller spatial subsets are considered (even when restrictions on the use of FADN data at higher resolutions can be overcome). The analysis presented here has demonstrated progress in developing methods for cross scale data integration linking biophysical and production systems data. The challenge remains though to find better ways of linking data on biophysical phenomena that are more frequently monitored or modelled at granularities compatible with field or farms (land cover) with agricultural production systems (land use or management) data that is, at best, available at regional or landscape scale.

The SMA approach developed in the project brought more depth to the analysis of the heterogenous EU agricultural systems by combining the multiple perspectives on feasibility and viability, across geographic scales and farm types. The 'sudoku approach' enabled different datasets to be brought together in a coherent accounting structure, and the use of the chord diagrams and relationship maps identified different types of (un)sustainable patterns within a single frame of reference. However, the approach as implemented was limited in terms of coverage of biodiversity issues and did not pursue correlation nor causation.

As illustrated in Section 3.4 and discussed in Section 4.1 and 4.3, the SMA was stronger on some aspects of SDG2 than others, being particularly limited with regard to the circular economy and energy due to limitations on the data in FADN. The overall QST, though, clearly illustrates in qualitative terms, the need to address policy coherence between CAP and energy; and the need to consider the embodied water, land and labour in agricultural commodities when considering the circular economy for the food sector. PNS encourages tolerance of explicitly recognised omissions, recognising that any attempt to represent a complex adaptive system will necessarily be partial.

The complexity, specificity and path dependencies involved in assessing the sustainability of agricultural production systems means that pursuit of detailed causal relationships can lead to taking too narrow a perspective (hypocognition) resulting in knowing more and more about less and less. The certainty that such narrow perspectives can give may be reassuring and is compatible with the norms of incremental policy change, but can also lead to "analysis paralysis" where irreducible uncertainty means that actions that need to be taken can be constantly delayed for lack of definitive evidence. The recent CAP evaluation found it hard to connect the effects of CAP instruments and outcomes (Alliance Environnement 2019a). Societal metabolic accounting tries to square this circle by highlighting issues where the lack of sustainability is so glaring that any incremental change is likely to be insufficient (i.e. finding the elephant in the room). This may mean showing where reframing of a single policy may be needed but can also mean identifying when there are conflicts or inconsistencies between combinations of (internally consistent) policies. This, the authors contend, is potentially more useful for strategic policy support than attempting to definitively tease out more specific cause-and-effect relationships in a complex, dynamic and heterogenous eco-social system. Any legitimate process of reframing though depends on having processes that promote and facilitate interactions between research, analysis, policy, and stakeholder communities, making joint efforts to identify and agree on the importance of issues; this can prove challenging.

The report shows that the promise of SMA (multi-scale, multi-dimension, spatial and functional decomposition) was to a substantial degree realised for the research team. However, it was clear that the most powerful presentations for stakeholders remained those of single dimensions and specific issues. Such presentations are necessary to address specific aspects or issues and to avoid overwhelming stakeholders with complexity. Yet since each one presents only a partial, and scale-dependent view of the system, and the process of view selection maybe as influential as any underlying data, colloquially, what we choose to look at, determines what we see. This is where ideally an iterative process of QST conducted with stakeholders would test and refine both framing of an issue and how that issue is presented. Such processes are though, time consuming and challenging to operationalise (see Section 3.5).

It should be remembered that even the many figures presented in Section 3.4 remain the 'tip of the iceberg' of what could have been generated from the data available within the agri-food processor. For example stakeholders recommended that analyses be presented as time series to help demonstrate the effects of policy change and hence build the perception that methodology is relevant to policymakers, but this would further amplify the complexity of information conveyed on the already complex chord diagrams and relationship maps.

4.4.6 Using QST and SMA

Overall, the QST cycle using SMA proved useful if challenging as a PNS form of policy evaluation. Feedback interviews suggested SMA remains a long way from being a mainstream method or toolkit for independent operational use by officials in DGs. The decision-support literature, e.g. McCown (2002), (Matthews et al. 2007) and (Matthews et al. 2008) highlights that good practice in the use of complex computer-based tools is to embed them within socially defined systems of decision-making. That is, the aim should not be to create a tool that replace either researcher or policymaker but rather one that serves as a boundary object, grounding deliberations and enhancing the quality of interactions between both sides (Jakku and Thorburn). Several individual stakeholders in the MAGIC QST process were confident and interested enough to suggest ideas for the researchers to analyse and illustrate using SMA, so there is reason to be confident that the ambitions of the research team were not misplaced, even if they were not fully realised.

Finally, it should be noted that doing QST has also resulted in learning for the MAGIC consortium, who have a much stronger understanding, albeit still limited, of the EU institutional arrangements and of ways to apply societal metabolism in real-world, rapidly evolving, policy contexts. The process of implementing QST resulted in uncomfortable knowledge (Rayner 2012) for the scientists in the mixed teams, as much as for the policy actors, something that will be further developed in publications. Areas for further research and learning are now summarised in Section 4.5.

4.5 Emerging questions for future research

The future needs arising from the previous sections first considers methodological research questions, then issues around SDG2 (externalisation and social justice) and ends with issues around the topic of sustainable agriculture.

4.5.1 Further methodological challenges, opportunities, and research questions

The insights from conducting QST has led to the following questions:

- How to embed a post-normal science process in a non-post normal world – and what are the consequences of doing so? Although the insight that QST is a relational process is a start, more attention needs to be given to how to operationalise QST in practice.
- How to give appropriate recognition and prominence to both the semantic and formal parts of QST, particularly in stakeholder interactions of limited duration (1-3 hours) and where further follow up interactions are challenging to achieve?
- How to move from semantic to formal parts of the QST process and back again. The 'reverse engineering' approach was useful, but it remains difficult to directly connect the qualitative and quantitative methods and insights.
- How to select, communicate and visualise complex outputs arising from complex methods? Including how to visualise time series data.
- How to operationalise the feasibility, viability and desirability lenses, particularly recognising that desirability is qualitatively different from feasibility and viability that can, to some extent, be benchmarked by quantitative standards.
- How to best to capitalise and connect the complementary but parallel post-normal science, science-policy interface and knowledge exchange/participatory modelling literatures? Identifying tensions between these literatures may help explain and deepen the understandings of the tensions found in trying to close the QST loop.
- To what extent would working in 'anticipation' mode be less 'threatening' and generate greater engagement with QST processes? This mode was used more predominantly in other MAGIC policy approaches, although with more limited stakeholder interaction. However, anticipation often relies on agreed assumptions that can be equally disputed by policy implementation actors.
- Will the proposed Farm Sustainability Data Network dataset (with more biophysical data) enable the embedding of energy, climate change and circular economic policy objectives into the SAM analyses?

4.5.2 Research to cover more aspects of SDG2

The discussion (Section 4.3) noted that most results refer to agricultural sustainability and production steps, pathways and systems but not supply systems or societal demand. The following tasks remain:

- Look at retail and social consumption practices as the analysis did not cover nutrition and societal demand (Figure 4).
- Consider how to implement SMA for the agri-food supply/value chain between the farm gate and the consumer.
- Further elaborate the use of embodied (e.g. land, labour and water) resources in imports and assess the draw on EU resources implied by exports. The focus to date in MAGIC has been more about simulation of reinternalisation of flows outside the EU, but an understanding of the pressures generated within the EU by commodities and food flowing out of the EU would also illustrate new tensions and trade-offs.
- Further analysis of import flows into the EU, considering where these are re-exported for use elsewhere within the EU and decomposing these flows and funds into farm types and FADN regions.
- Consider 'Zero Hunger' within the EU – the current position is to focus on obesity within the EU with an apparent assumption that there is no 'hunger' in EU. Yet poor nutrition though

over consumption can co-exist with food insecurity – as seen through the rise in food bank use since the financial crash in 2008.

- Improved understanding of systemic lock-in and path dependencies in production-consumption systems. This requires innovation in environmental governance, as existing approaches have limited in ability to generate change (European Environment Agency 2020; Waylen, Blackstock, and Holstead 2015). This emphasizes the role for government to steer and enable a policy-mix that links knowledge with action and requires new institutional arrangements.
- Bring into SMA and QST a missing dimension of social justice as elaborated below.

4.5.2.1 Social Justice

The EU recovery plan (European Commission 2020a) highlights the need for a just recovery, including paying attention to fair wages, work practices, access to work for young people and ending the race and gender pay gaps. Given the predominance of family labour and the suggestion of low-waged seasonal work in our data, more attention to these issues of intersectionality and social justice within the agri-food strategy would be warranted. The proposed CAP objectives cover generational renewal and fair wages but are less explicitly focused on other dimensions. The Commission does identify links between SDG2 and SDG5 (gender equality) although the presentation tends to be on empowering women in the global South rather than attention to gender dynamics within the EU's farming and food processing sectors.

A preliminary literature review suggests that equity, equality, justice and fairness are often used interchangeably in the sustainability literature (Klinsky 2009). Justice is accepted as central to the well-functioning of society with fairness being an expectation in day-to-day interactions (Gross 2007). In the MAGIC conceptualisation of desirability, we consider both procedural justice and distributive justice. The former considers whether a decision was made in an appropriate fashion. (Simcock 2016) gives a useful summary of what is required to enable procedural justice, and why procedural justice is often contested. These controversies explain why procedural or distributive justice are often entangled. The latter, distributive justice, extends beyond traditional views of social justice focused on goods and benefits, to wider ideas associated with social, cultural and institutional conditions, as suggested by (Schlosberg 2004). In this context, the terms 'outcome fairness' and 'outcome favourability' (Skitka 2003) are useful, as they help to focus attention on how actors perceive and accept the outcomes of a policy. MAGIC takes a critical perspective at odds with standard ecological modernisation framings (Sonnenfeld and Mol 2011), recognising that claims to being just (see for example CAP objective on 'fair' income, Section 1.1.4) are generally framed in the interests of the ruling elite (Harvey D. 1996). Instead, a future analysis could place the emphasis on inequality and marginalisation at the centre, to understand the intertwining of social and environmental outcomes in ways that are more appropriately considered by contextualised understanding of how outcomes affect marginalised actors. The focus is on the ethics of emotion, care and affect (Olson, Ortiz, and Reddy 2020), which requires different forms of measurement beyond standard quantitative methodologies of costs and benefits. However, this returns us to the challenge, highlighted in Section 4.4, whereby policy actors whose role is to implement and stabilise the status quo, are unlikely to wish to engage with a project which aims to refocus attention on the poor and marginalised and priorities their empowerment. As such, MAGIC's attempt to focus on desirability has come up against the central challenge of whether social and environmental justice is about ensuring universal, or at least 'societal' principles are met through universal and standardised institutional arrangements available to all, or a recognition that justice may require unequal institutional arrangements to compensate the disadvantaged, something often perceived by others as 'unfair'.

4.5.3 Research on Sustainable Agriculture

This section is more limited, given that most of the existing effort has been on this part of SDG2. However, three areas have arisen that need more attention.

- Attention to the distribution of CAP payments and the equity of the outcomes in economic and social dimensions. The data suggest that CAP payments tend to go to large, high intensity, generally specialised farms; and that some farm systems' profitability is dependent on CAP. This raises questions about how such support is justified. In particular, the distribution of Pillar I and Pillar II payments between FADN regions and farm types needs more attention, given the existing narrative that more uptake of Pillar II instruments could ameliorate negative impacts of agriculture. Exploring the gender dimension, with reference to SDG5, would also be useful.
- Improve understanding of land management outcomes through combining FADN with the EU Farm Structure Survey data – this may give a better way to characterise the built infrastructure and machinery use within the SMA.
- Including changes in patterns of land take, land abandonment and habitat fragmentation (European Environment Agency 2020). These data are not available in FADN but are available via Eurostat, so consideration of the potential for data integration is needed. This may also involve considering the impact of financial investment in land on land values and the knock-on effects on access for new entrants.
- Attention to the role of biofuels, as a source of pressure on the available land area, beyond those already covered other MAGIC project deliverables, in terms of its interplay with SDG2 and beyond.

The report now concludes by summarising the main findings and their implications.

5 Conclusions

This report offers a pan-EU socio-ecological assessment of the EU agricultural and agri-food system. The analysis presented illustrates the character of the EU agricultural production systems by farm type and across FADN regions, considering both the inputs for production systems and the pressures arising on environmental funds (the biosphere), and socio-economic funds (the technosphere). The MAGIC outputs confirm other environmental, economic and social findings, that the EU's agricultural production systems are often putting severe pressure on these funds and are unlikely to be sustainable when considered over the long term and against planetary boundaries. The distinct contribution made by this assessment is the cross-level coverage (combining geographical and sectoral elements) for both environmental and socio-economic issues, all within a coherent and systemic approach of societal metabolism accounting.

One of the main objectives for the "Moving Towards Adaptive Governance in Complexity: Informing Nexus Security" (MAGIC) project was to bring the theoretically driven interests regarding governance in complexity into a real-world policy setting. This report considered EU progress towards the UN Agenda 2030, especially SDG2, target 2.4 (sustainable agriculture), using the CAP as a nexus policy. The report illustrates the evolution of the CAP and the attempts to achieve sustainability within conventional green growth paradigms. The report focuses on the gap between the scale of the challenge confronting the EU and the world, and the often cautious response by policy actors seeking to use incremental policy changes to bridge the gap between the current situation and the sustainability goals espoused by the formal institutions and their electorates.

Within the EU, this incremental approach is likely to jeopardise delivering the climate & energy policies, the Water Framework Directive, and the 2030 Biodiversity Strategy goals. There are also business viability and other social pressures arising from the current agri-food system, illustrating that achieving sustainability is not a straightforward trade-off between environmental and social priorities. The analysis suggests that current states do not match those desired from CAP and other policies (WFD, Natura 2000) and that the SDG2 objectives, particularly the target for sustainable agriculture (2.4, see Table 1), is unlikely to be delivered under current arrangements. This is despite EU agricultural policy becoming more and more focused on all aspects of sustainability, responding to the twin climate and biodiversity crises.

The EU situation may not be ideal, but often the EU is still argued to be a global leader in trying to achieve sustainability. This report suggests however that any consideration of EU sustainability must include both the pressures within the EU and the pressures that EU agriculture places on the rest of the world. The report confirms the importance of the interaction between internal EU policy and EU external affairs, trade and development policy – and societal metabolism illustrates the often-hidden dependence on material flows to (imports) and from (exports) the EU. Using an SMA approach to undertake a systemic characterisation of the funds and flows associated with the metabolism of agri-food systems in EU (including processing and consumption) would also help understand the degree to which the existing agri-food system can become more 'circular'.

The report suggests that to understand the sustainability of the EU agricultural system, it is important to complement economic statistical data with more biophysical statistical data, generated using a common accounting methodology. This enables a full, strong, sustainability assessment to be generated, that considers the 'three pillars' of sustainability that the Commission policy actors referred to, but in a systemic manner which makes trade-offs and dependencies in time and space visible. The application of societal metabolism accounting using the existing Farm Accountancy Data Network illustrated some limitations – changes are required to support the transition to a Farm

Sustainability Data Network, as promoted by the Commission's Farm to Fork Strategy (European Commission 2020d). Overall, the report suggests that natural capital cannot be substituted indefinitely, without severely restricting the resilience of the global socio-ecological system. Despite the ongoing divisive geopolitics involved in trade and security negotiations, the UN SDGs recognise the essential interdependence of all nations on the global ecosystem.

Central to the 'MAGIC' approach is the use of the Quantitative Story Telling cycle, including engaging policy actors, selecting themes of salience to policymaking, running societal metabolism accounting at the pan-EU scale and interpreting findings with policy actors. Doing QST with EU policy actors linked to a concrete strategic policy goal (SDG2) revealed that QST is more complex and iterative than presented in Figure 3, involving many micro-decisions, as well as revealing some element of path dependency as the data and accounting formalities condition what stories can be told. The assessment was challenging to calculate, challenging to communicate, and challenging to hear by policy stakeholders. The findings often generated 'uncomfortable knowledge' by asking policy actors to question the 'taken-for-granted' ideas about progress and the evaluation of policy. The lessons learnt suggest that not only does policy need to reframe problems (the traditional PNS response); but also how, and at what scale, should policy responses be pitched. This may mean refocussing policy framings from lower SMA levels (the specifics of production steps) to systemic issues around supply systems and consumption practices.

However, there were also challenges in using QST to engage with policy. The approach was to draw attention to unsustainable patterns without claiming causality to illustrate the need for change from the status quo. For example, the findings raise issues of resilience and diversity from subsidies encouraging specialisation; unsustainable draw on green water and soil; and the tendency to trade-off these pressures for economic development. Policy actors found this hard to respond to, given their mandate was to use evidence within existing institutional arrangements and specific policy levers. This situation generated a series of paradoxes or tensions about how to operationalise QST in practice, regarding how to be both useful and critical; and how to focus on the whole socio-ecological system whilst being salient to policymakers' individual mandates and responsibilities. A challenge yet to be overcome was to find the policy actors, or assemblage of actors, who explicitly identified themselves as legitimate stakeholders for the 'whole' agri-food system across the EU.

This report therefore adds to the body of research saying that business-as-usual is not sufficient to deliver SDG2. It combines a PNS approach to policy analysis with societal metabolism accounting. The report recognises both the innovation and the difficulties in operationalising a post-normal approach to these complex and traditionally distinct scientific endeavours. As such it provides both evidence that transformation is needed across all aspects of the agro-food system, and evidence regarding the strengths and weaknesses of using QST to support such a transformation.

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Appendix I – Evaluation form used in ‘closing the loop’ of the QST cycle.

These questions ask for your views on our ‘MuSIASEM’ method and its application in relation to SDG2, and your reflections on the implications for current and future agri-food systems. We will use this information – together with records of discussion during the seminar – to gauge reactions to our analyses, update our understanding of debates on sustainable agri-food systems, and help shape our further analysis. We also request your feedback on how we presented and run our seminar today: we will use this to inform and improve our future engagement.

1. Overall, did you find this meeting interesting?	Not at all	Somewhat	Interesting	Very interesting
	☐	☐	☐	☐
Please can you explain your answer?				
2. What, if anything, did you learn from today’s meeting				
	Nothing	A little	Some	Quite a lot
a) About analytical approaches	☐	☐	☐	☐
b) About Europe’s contribution to SDG2	☐	☐	☐	☐
Please can you explain your answer?				
3. What, if anything, might you do differently after today?				

4.	Thinking about today's discussion regarding the draw on resources *within the EU*, do our results suggest that the current agri-food system is:					
a.	Bio-physically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK (Don't Know) ☐
b.	Socially and technologically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK ☐
c.	Culturally and politically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK ☐
	Any comments					
5.	Thinking about today's discussion regarding its draw on resources *beyond the EU*, do our results suggest that the current agri-food system is:					
a.	Bio-physically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK (Don't Know) ☐
b.	Socially and technologically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK ☐
c.	Culturally and politically sustainable	Not at all ☐	Somewhat ☐	Mostly ☐	Completely ☐	DK ☐
	Any comments					
6.	What policy changes are needed, if any, to fully support and enable achieving SDG2?					

Extent of change needed	None ☐	A small amount ☐	Some ☐	Radical change ☐	DK (Don't Know) ☐
Comment about type of changes needed and to which policies					

7. Are there any particular issues or topics that you might be interested to see analysed using a societal metabolism approach? Can you say why this might be interesting or useful for your job and/or policy support?

8. Please suggest any colleagues or other contacts who might be interested in MAGIC, i.e. to learn about its methods, share outputs, or to discuss future developments.

9. Please rate the following practical issues:	Very poor	Poor	Good	Very good
Pre-meeting communication	☐	☐	☐	☐

Location in Schuman	☐	☐	☐	☐
Structure of the seminar	☐	☐	☐	☐
Facilitation on the day	☐	☐	☐	☐
Materials provided	☐	☐	☐	☐
Quality of interaction	☐	☐	☐	☐
Please add any comments about these aspects, or any other points to help us engage better in future:				

Thank you for your input! Feel free to make any further comments below, or in person or by email.

Appendix II: Feedback interview guide

H2020 MAGIC - Reflecting on the MAGIC project and Quantitative Story Telling

Our interest is in how you understood and experienced the MAGIC project and Quantitative Story-Telling (QST) process, including consideration of whether the stories presented were relevant, interesting, and/or thought-provoking.

- In particular, we are interested in learning about what (if anything) QST ‘did’ for your ideas or work, and how the QST and societal metabolism accounting (MuSIASEM) process could be improved.

Questions we would like to discuss include:

1. **Has sharing insights from QST stimulated you to think about the issues in new ways?**
    - Were any new thoughts, ideas or actions stimulated by the MAGIC project, and if so, what were they and why?
    - If not, why not (e.g. relevance? Practical challenges? Other?)
2. **In terms of how QST was presented to you, what worked well or didn’t work well?**
    - do you remember the meetings where we presented QST?
    - what is your view on the narratives/themes we presented and how they were chosen?
    - did you feel able to talk about your reflections on the dominant narratives shaping policy?
    - What format is mostly likely to enable understanding of data and discussion of responses and implications?
3. **Overall reflection on MAGIC project**
    - Will MAGIC have any long-term impact (positive or negative) for you or others?
    - How has this project compared to any other research projects you have worked with? E.g. were interactions with researchers interesting for informing your work, prompting new ideas and thinking about problems?
    - Is there anything else you feel is important to consider when we are learning lessons about our approach?

Appendix III: Slides presented when closing the QST Loop

The slides presented at the November 2019 workshop can be accessed here: https://www.hutton.ac.uk/sites/default/files/files/projects/MAGIC/MAGICSDG2_SeminarSlides_191121.pdf

The slides presented at the European Parliament breakfast can be accessed here: https://www.hutton.ac.uk/sites/default/files/files/projects/MAGIC/20_01_30_MAGIC_EP_breakfast_slides.pdf

The slides presented to the EEA via Webinar can be accessed here: https://www.hutton.ac.uk/sites/default/files/files/200602%20EEA%20Webshop%20slides%20for%20sharing.pdf

For an overview of the project outputs including reports from these interactions, please see: https://www.hutton.ac.uk/research/projects/magic