Using deliberative societal metabolism analysis to analyse CAP's delivery of EU sustainability and climate change objectives.

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Abstract

This paper contributes to the conference discussions of (1) "*what are the trade-offs and synergies between the economic, environmental and social dimensions of the Common Agricultural Policy (CAP) as a policy geared towards sustainability"*; and (2) how to measure the performance of agriculture at a range of scales. Specifically, we assess whether there are tensions for CAP policy between enhancing productivity and the provision of public goods. Our insights are derived from an EU Horizon 2020 project, Moving Towards Adaptive Governance in Complexity: Informing Nexus Security (MAGIC) exploring the robustness of policy narratives in the water, energy, food and environment nexus.

As highlighted in the conference objectives, assessing the role of the CAP in delivering sustainability requires taking multiple, non-equivalent perspectives (e.g. geographical scales or structural hierarchies). The conduct of these multi-perspective studies is guided by the concepts of *societal metabolism* analysis. The analytical focus is thus on understanding the mix of biophysical and socio-economic resources needed to maintain social-ecological systems (e.g. food and farming systems) and the degree to which these are met locally, highlighting where there may be dependencies on other systems or externalised impacts.

We conducted transdisciplinary research with policy makers using Quantitative Story Telling (QST). The QST process has a phase of qualitative analysis of the institutional and semantic framings of CAP policy narratives, followed by formal quantification of the robustness of policy narratives using the MuSIASEM toolkit for societal metabolism analysis. Interpretation of these formal analyses, with stakeholders in DG Agri and other EU institutions, *closed the loop*. The results of this analysis (and of other analyses for Biodiversity, Circular Economy, Energy Efficiency, and Water Framework Directive) are available via the MAGIC document repository.

From the semantic qualitative phase, the narrative selected as the basis for formal analysis was: "*CAP aims to ensure European agricultural competitiveness in the world market and aims to deliver public goods such as biodiversity conservation, water quality and climate change mitigation. These aims are in opposition*". The formal societal metabolism analysis was pan-EU, focusing on key aspects of EU farming systems. These characterized imports and exports of agricultural commodities, the relative intensities of inputs use in production systems and the aggregate impacts of production systems on environmental indicators. Farm Accountancy Data Network (FADN) data and Eurostat CAP impact metrics already include variables that can support these pan-EU societal metabolism analyses. Adding more bio-physical quantities to those existing within FADN, particularly for inputs and outputs, would enhance its analytical value, particularly for identifying externalisation and pressures on the environment.

The paper presents the results of four analyses relevant to the narrative on tensions between competitiveness and public goods:

1. Analysis of international trade in agricultural products highlights the dependence of EU agriculture on external resources, e.g. feedstocks. These external resources increase the competitiveness of EU agriculture by allowing a more profitable mix of production systems to be undertaken within the EU. Yet, their production can both undermine public-good provision beyond Europe’s borders and threaten domestic food security.
2. Within the EU despite some opportunities for increases in efficiency of resource use, the magnitude of outputs from farming systems are still in most cases tightly coupled to levels of inputs (e.g. fertilisers), which in turn may reduce delivery of public goods (e.g. unpolluted water). This suggests that if CAP is to achieve a more sustainable balance of competitiveness and provision of public goods, then a portion of the resources devoted to CAP may be better deployed to reduce the societal demands on the farmed areas of the EU and beyond.
3. An analysis of Nitrogen-related emissions illustrates the importance of extent data (e.g. total emissions), to complement to the more usual focus on intensity metrics (e.g. emissions per ha). The cumulative effect of lower-intensity but large-extent emissions could undermine delivery of EU commitment to reducing N based impacts on water and air quality including cutting greenhouse gasses (GHG’s). This might suggest, for GHG emissions at least, the need for CAP policy to consider more closely farming systems with lower intensity but larger extents of N related emissions.
4. A soil erosion analysis suggests a key challenge, since in nearly all member states soil erosion in crop-based production systems exceeds the rate of soil renewal processes.

These analyses illustrate tensions between the pursuit of competitiveness and delivery of public goods: however, policy stakeholders who discussed the societal metabolism analyses were not necessarily convinced by our findings. This reluctance is unsurprising given the unconventional nature of the societal metabolism analysis; and that the results critiqued existing policy without offering immediate solutions.

The QST process does though suggest the need to question the policy narratives within the CAP that prioritise efficiency and economic growth over those facilitating sustainability transition. This requires analyses that focus on what underpins our systems of production and makes space for deliberation on systems-based solutions. Our analysis suggests that it will be challenging to make marked progress for previously stated CAP objectives and the ambitious objectives suggested for CAP post 2020. It may be better to acknowledge the limits of CAP and acknowledge the difficult trade-offs, rather than accepting a justification narrative for CAP that could undermine its credibility and legitimacy.

1 Questions addressed

There is a huge volume of research on the Common Agricultural Policy, given its longevity (introduced in 1962) and its numerous evolutions regarding its objectives and its delivery mechanisms, for example see Daugbjerg (2009). The CAP is associated with many outcomes that have been assessed as positive or negative depending on the standpoint. These outcomes include food production, commodity trading, environmental protection and rural development. The effectiveness of the CAP regarding these outcomes is subject to ongoing scrutiny and proposals for reform (European Commission, 2019). Some have argued that the CAP tries to tackle 'wicked problems' – problems that are highly interconnected, persistent and very difficult to resolve, see Kuhmonen (2018). Debates over what to achieve with the CAP; and how well it is delivering these outcomes, should thus be expected.

In this paper we assess whether there are tensions for CAP policy between enhancing productivity and the provision of public goods. Our insights are derived from an EU Horizon 2020 project (MAGIC) exploring the robustness of policy narratives in the water, energy, food and environment nexus.

This paper contributes to the conference discussions of (1) "*what are the trade-offs and synergies between the economic, environmental and social dimensions of the CAP as a policy geared towards sustainability*"; and (2) how to measure the performance of agriculture at a range of scales. The first objective is achieved through presenting some selected examples of outputs from the analysis. These cover multiple domains (trade, production systems efficiency and their association with Nitrogen emissions and soil erosion). This gives a flavour of the flexible and comprehensive nature of the analysis within the MAGIC project. The second objective is achieved through setting out the approach and methods that allow cross-scale analysis both geographically and via farm system decomposition.   Both objectives were explicitly selected as they offer pan-EU insights to those evaluating CAP in terms of delivering EU sustainability and climate change objectives.

2 Concepts and theories referred to

As highlighted in the conference objectives, assessing the role of the CAP in delivering EU sustainability and climate change objectives requires taking multiple, non-equivalent perspectives (e.g. geographical scales or structural hierarchies). The conduct of these multi-perspective studies is guided by the concepts of *societal metabolism* analysis (Gonzáles de Molina and Toledo, 2014). The analytical focus is thus on understanding the mix of biophysical and socio-economic resources needed to maintain social-ecological systems (e.g. food and farming systems) and the degree to which these are met locally, highlighting where there may be dependencies on other systems or externalised impacts. Societal metabolism is thus a framework that allows complexity to be analysed or simulated for multiple questions, across multiple geographical, sectoral or administrative scales, whilst providing coherence of approach to allow the outputs of analysis to be interpreted by stakeholders. The quantitative engine used for conducting the societal 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. This has been applied in a variety of settings including Water, Energy, Food and Environment (WEFE) Nexus studies, see (Giampietro et al., 2014).

Societal metabolism analysis focuses on the funds used 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). These funds are typically land, 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 analysis is thus a biophysical accounting framework, maintaining the description of funds and flows in non-equivalent units throughout the process of analysis. This avoids having to convert indicators of funds and flows into a single unit (e.g. financial values); allowing them to remain non-equivalent and non-substitutable. This places societal metabolism in the domain of strong sustainability (Ekins et al., 2003).

A societal metabolism analysis considers both the extent and intensity of resource, this is essential for identifying cases of Jevons Paradox (Alcott, 2005; Polimeni et al., 2010) when despite increases in efficiency, the overall take of resources increases. Extent based metrics are most significant when downscaling from the global scale *safe operating space* concept of Rockstrom et al. (2009) to the national scale where it becomes more possible to define *fair shares* and pollutant concentrations against locally tolerable limits (Häyhä et al., 2016).

A societal metabolism analysis is conducted simultaneously across scales (geographical or hierarchical/functional). Taking more than one non-equivalent perspective helps to better understand the complex set of drivers, pressures and processes that confront policy making in the WEFE nexus. For example, it is important to consider more than one level to fully understand how the system functions. Figure 1 presents a set of non-equivalent perspectives for a WEFE system. Focusing on *production steps* (management measures) or overall *societal demands* (for food) alone doesn't explain why and how challenges and trade-offs are played out in WEFE systems. The cross-scale analysis also permits an analysis of *externalisation* whereby the performance of a system at a focal level is dependent upon activities beyond the system boundary. This relates to the concept of *externalities* as a cost shifting success in ecological economics (Martinez-Alier, 2005).

Given the number and complexity of the entities being studied across these levels there is clearly the potential need for mechanisms by which these results can be synthesized to provide meaningful insights e.g. for policy makers. Each level potentially generates vast amounts of data and possible indicators for policy-making. Therefore, in keeping with the overall philosophy of using societal metabolism as a coherent but flexible framework that helps see the sum of its parts, benchmarking is used. In MAGIC to date, the benchmarks used were Feasibility and Viability (described below).

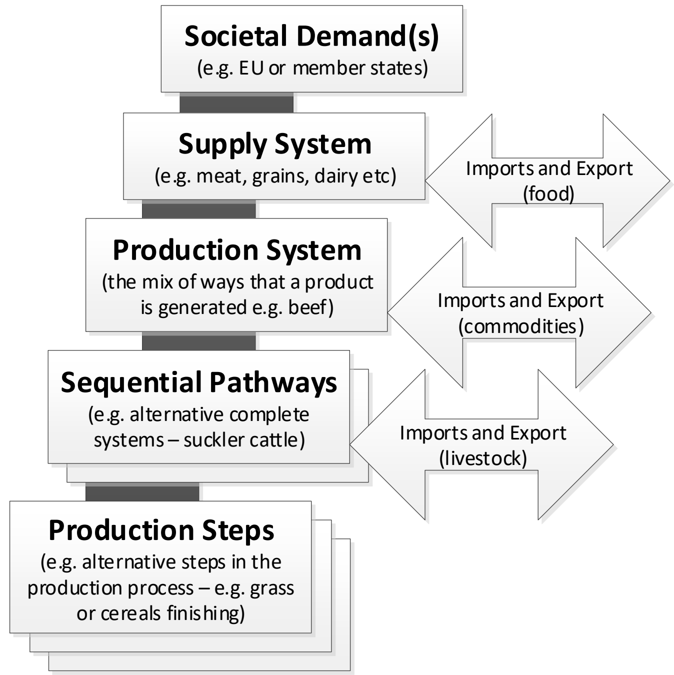

Figure 1: Example of non-equivalent perspectives for a water-energy-food system

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 is also the intersection with externalisation and 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.

The wider MAGIC project has combined the use of a societal metabolism approach with a post-normal science perspective (Funtowicz and Ravetz, 1993), that recognises that knowledge is contested, dynamic and held by multiple actors including non-academic stakeholders. Post-normal policy support means reflecting on and questioning what is at stake and for whom in any policy-making process.

The overall CAP analysis is also underpinned by theories of interdisciplinary science recognizing the equal importance of semantic (qualitative) and formal (quantitative) components, and the need to reconcile the challenges of so doing (Lele and Norgaard, 2005). The research seeks to engage with multiple perspectives to understand the institutional context that is shaping decision-making (Mayumi and Giampietro, 2006). Therefore, the approach also reflects the diversity of the research team's experiences and insights, for example those from computer-based decision support (Matthews et al., 2007) and participatory research (Kowarsch, 2016) guided us in how to embed analysis in socially defined processes of meaning making, recognizing the importance of formal and informal institutions and political power. This embedding is operationalised through adopting a transdisciplinary research process called Quantitative Story Telling (QST).

3 Methodology used

QST recognizes that there is unavoidable scientific uncertainty and value plurality in decision making within the nexus of water, energy and food policies. By providing an alternative set of tools and processes, QST seeks to promote progressive thinking about nexus/sustainability issues by:

1. Recognising policy inertia whereby absence of evidence allows inaction and maintenance of the status quo;
2. Recognising the importance of articulating the nature of conflicts that may lie beneath seeming consensus;
3. Recognising the value plurality that shapes which evidence is accepted and how evidence is interpreted.

This means that the semantic aspects of science for policy in QST necessarily have equal or greater weight compared with the formal (quantitative analysis or modelling) in determining the conduct of the science for policy.

The QST process has a phase of qualitative analysis of the institutional and semantic framings of CAP policy narratives, followed by formal quantification of the robustness of policy narratives using the MuSIASEM toolkit for societal metabolism analysis (Giampietro et al., 2017). Interpretation of these formal analyses, with stakeholders in DG Agri and other EU institutions, *closes the loop* (see the stages of QST in Figure 2, below).

Ideally each of the QST stages is undertaken in *Mixed Teams* that include researchers having both policy and domain knowledge (e.g. land use, water, biodiversity), and backgrounds in biophysical, social and computational sciences, coordinated by staff with experience of working across the science policy interface.

3.1 QST –ideal steps

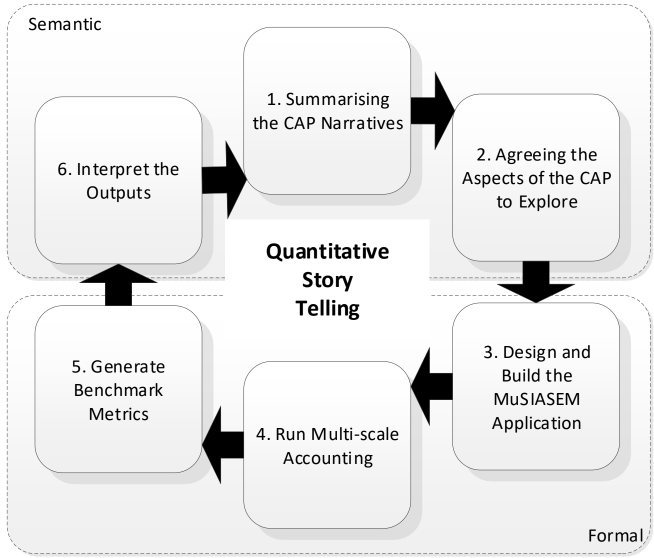

Figure 2: The process of Quantitative Story Telling

1. *Summarizing the Narratives* – this identifies the narratives which are of interest to policy makers and other stakeholders. The phase will also assess which narratives are compatible with MuSIASEM analysis and sees interactions with policy and other stakeholders.

2. *Agreeing Aspects to Explore* – this stage sees the development of a much more specific shared understanding of what will be analysed and how (i.e. building a conceptual framework for the analysis). 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 must be represented (semantic definitions) and other choices that will shape the later quantitative analysis (e.g. setting system boundaries, scales of analysis and useful indicators).

3. *Design and Build a MuSIASEM Application* – this stage sees the formalization (representation in the forms used in the process of analysis) of the systems that the narrative(s) address (e.g. a water body, an agri-food supply chain or a country). This stage builds an analytical framework that, while it represents a specific type of system, is at least partially reusable for any instances of that type.

4. *Run Multi-Scale Analysis* – in this stage the MuSIASEM Application from stage three is populated with quantitative data such that it becomes a complete formal representation of the system of interest and can be used to test narratives about the current state (*diagnostic mode*) and possible alternatives (*simulation mode*).

5. *Generate Benchmark Metrics* – In this stage, summary metrics are generated that assess the feasibility (within biophysical limits) and viability (within institutional limits – e.g. socio-economic limits) of the narratives. The process of summarizing and communicating the metrics must convey both quantitative and qualitative (semantic) uncertainties and sensitivities. This is essential as the outputs from the analysis need to be salient and credible if they are to be influential in conceptual or instrumental terms.

6. *Interpret the Outputs* – 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 here as a linear process (even if iterative) – it is anticipated that there may well be occasions, 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 of QST is not, however, to pursue ever-greater depth of partial analysis but to complete the QST cycle and generate meaningful outputs that stimulate deliberations with stakeholders.

3.2 Caveats to the methods and results

For the CAP analysis it should be noted that many of the ideas of societal metabolism analysis have been exploited without necessarily using the specific tools or formalisms of MuSIASEM. This means the analysis is MuSIASEM informed rather than fully implemented. Note also that for this analysis the assessments of the Feasibility and Viability benchmarks have been qualitative and based on informal assessments of the analyses presented in Section 4

4 Results obtained

The results of the CAP analysis (and of other analyses for Biodiversity, Circular Economy, Energy Efficiency, and Water Framework Directive) are available via the MAGIC document repository. The CAP analysis results are reinterpreted here in the context of the conference themes.

From the semantic (qualitative) phase, the narrative selected as the basis for formal analysis was:

CAP aims to ensure European agricultural competitiveness in the world market and aims to deliver public goods such as biodiversity conservation, water quality and climate change mitigation. These aims are in opposition.

This narrative was a synthesis of ideas expressed in interviews with a wide range of current and former Directorate General (DG) staff and other EU institution staff. It is not a quote from a single individual or group, nor was it a consensus narrative agreed on by all stakeholders. It was noted from the outset as being controversial and explicitly not representing the public position of any EU or EC institution. Yet it was the narrative ranked more highly by those stakeholders who expressed a preference and was tractable for a societal metabolism analysis, so it was chosen to shape the formal aspects of the societal metabolism analysis.

Competitiveness is a multilevel, context dependent and contested concept, and is not necessarily a panacea objective on which to base a sustainable agriculture or environment policy. In the MAGIC analyses, competitiveness was considered from two perspectives, first the role of the EU in global trade in agricultural commodities and food, and the second comparing, on a biophysical basis, the productivity of sectors between and within EU member states. The former was driven by the need to addresses the "world market" aspect of the narrative and the latter served to open interpretations of how, for different sectors, competitiveness links with efficiency and environmental pressures. The societal metabolism analysis recognises two types of efficiency are in play. Type 1 - *Do more with less* (the minimum entropy principle) but notes the need for care when assessing such efficiency so that it is not being achieved simply by displacing necessary but less productive activities beyond the boundary of the system being assessed – externalisation. Type 2 - *Do more with more* (maximising the flux) here efficiency is achieved through economies of scale particularly on making viable the investment in large scale infrastructures. While viable within the technosphere such enterprises may draw on natural resources at unsustainable volumes or rates (locally or globally) and generate local pollution burdens, soil damage and biodiversity loss that cannot be sustained.

The formal societal metabolism analysis was pan-EU, focusing on key aspects of EU farming systems. These characterized imports and exports of agricultural commodities, the intensities of inputs use and the aggregate impacts of production systems on environmental indicators at member state level.

Farm Accountancy Data Network (FADN) data and Eurostat CAP impact metrics already include variables that can support these pan-EU societal metabolism analyses. However, they continue to be limited in scope and partial in coverage. Adding more physical quantities (such as the energy mix used, the quantity of irrigation waters used or power capacity of machinery) within FADN would enhance its analytical value, particularly for identifying externalisation and pressures on the environment.

In the following sections the paper presents the results of four analyses relevant to the narrative on tensions between competitiveness and public goods.

4.1 Trade as an expression of competitiveness

Analysis of international trade in agricultural products highlights the dependence of EU agriculture on external resources, e.g. feedstocks. These dependencies are perceived to increase the competitiveness of EU agriculture by allowing a more profitable mix of production systems to be undertaken within the EU, but their production can undermine public-good provision beyond Europe's borders.

Figure 3 highlights that in terms of tonnages, cereal, dairy and meat dominate exports. This is seen as an indicator of the first dimension of competitiveness given it demonstrates that the EU is successfully trading on the world food commodity market. The use of tonnages fits with the ideas of societal metabolism and the funds needed to generate such flows. The relative magnitudes would of course be very different in financial terms and the dairy exports are shown as milk equivalents rather than the variety of forms in which they occur. The generation of a tonne of dairy products will also involve a much larger overhead in biophysical terms given the need to maintain dairy cows and the relative inefficiency of livestock in the generation of calories. The apparent dependence of such exports on imported resources is clear from the imports side of the chart where the great majority of the materials imported are used as feed materials for EU livestock. However, it is increasingly argued that the cultivation of such feed materials, particularly in Latin America, has negative consequences on soil health, water quality, carbon sequestration and biodiversity.

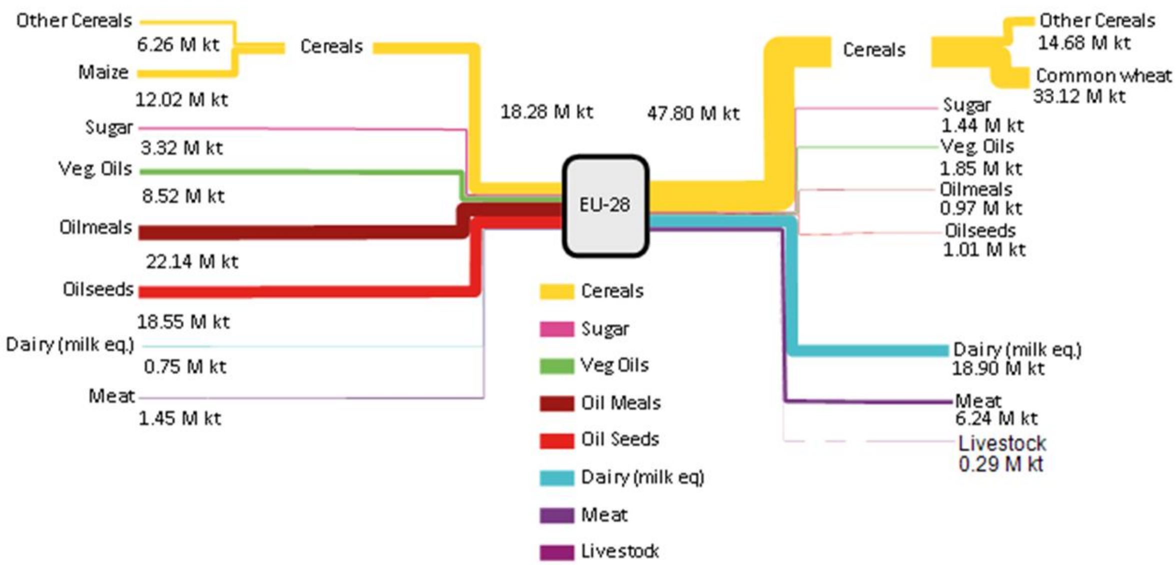

Figure 3: The imports (left) and exports (right) of foodstuffs and other agricultural commodities for the EU in 2016

4.2 The biophysical basis of competitiveness of sectors

Comparing on a biophysical basis the productivity of sectors between and within EU member states, FADN provides a small number of output intensity variables. These are yields per hectare of wheat and maize and milk yield per cow. Given the importance of wheat for exports (see Figure 2 above) and for EU food security, wheat yields were used. While the public FADN dataset has cereal area (SE035) the specific area of wheat isn't available. This meant that the analysis made use of intensities alone (for both inputs and outputs). The area of specific crops was noted by DG Agri stakeholders as being available in the full FADN dataset and could be brought in to allow consideration of extent if needed in any follow up analysis.

For input intensities, nearly all are quantified in financial terms but only fertilisers (N, P and K) are measured in physical terms (and in the analysis presented N has been used). The N, P & K data are integrated consistently with subsidy and other financial data within FADN, but they are relatively new. This meant that no time series are available; the dataset was incomplete at the time of analysis (November 2018) and the reliability of the data is unknown to the research team. Note that where input values were missing but yield values were available then these were included to give an impression at least of the intensity of outputs and the support being provided. The range in which the input intensity is likely to fall could also be inferred to some degree from the charts generated in the analysis.

The chart in Figure 4 presents for wheat the relationship between intensity of inputs (N in kg/ha) and intensity of outputs (wheat yield in 00's kg/ha summarised for specialist cereals (Sp.COP) businesses in each member state. The markers are for the total subsidy in Euros per ha. It should be observed, however, that particularly when considering changes in productivity over time the relative mix of "good quality" and "marginal" agricultural land used can heavily affect the technical characteristics (calculated per hectare) obtained by averaging statistical data. In relation to this point, set-aside policies tend to increase productivity, not for biophysical reasons, but by removing the less well performing crop-fields from the accounting.

For wheat there is a clear positive relationship between N inputs and wheat yield. At the production systems level there is no *free lunch* and there is in effect a pareto front beyond which the returns per unit of input cannot go. There is, however, a significant variation in the intensity with which Sp.COP businesses are conducted – that is there are different systems (or more likely mixes of systems) that are preferred or possible in different member states. The member states along the front seem to be achieving outcomes in production terms that are pareto-optimal but with a strong trade-off in intensity that may well link to their provision of public goods from the mix of production systems present.

That said, for any yield value there are a range of inputs (points to the right of the pareto front) which means that there may be room for improvements in the efficiency of inputs (perhaps more precise use of inputs), but this may imply greater use of capital which may not be viable. Improved precision could mean more yield for the same inputs (moving up towards the front) or more yield for the same inputs (moving left toward the front). Being behind the front may also be the result of weather events. For example, the yield for France was noted as being atypical (too low) as the result of drought in 2016, though no N rates are available. There is thus some potential for increased production or reduced inputs though efficiency gains but in the absence of wheat production displacing other activity to increase the area, then most increase can only be the outcome of greater reliance on inorganic N fertilisers. This would have implications both for how the energy needed for such inputs can be provided and the degree to which negative consequences for the biosphere (water quality and biodiversity loss) could be mitigated; which also suggests such a shift may not be feasible in terms of protecting stocks of natural capital.

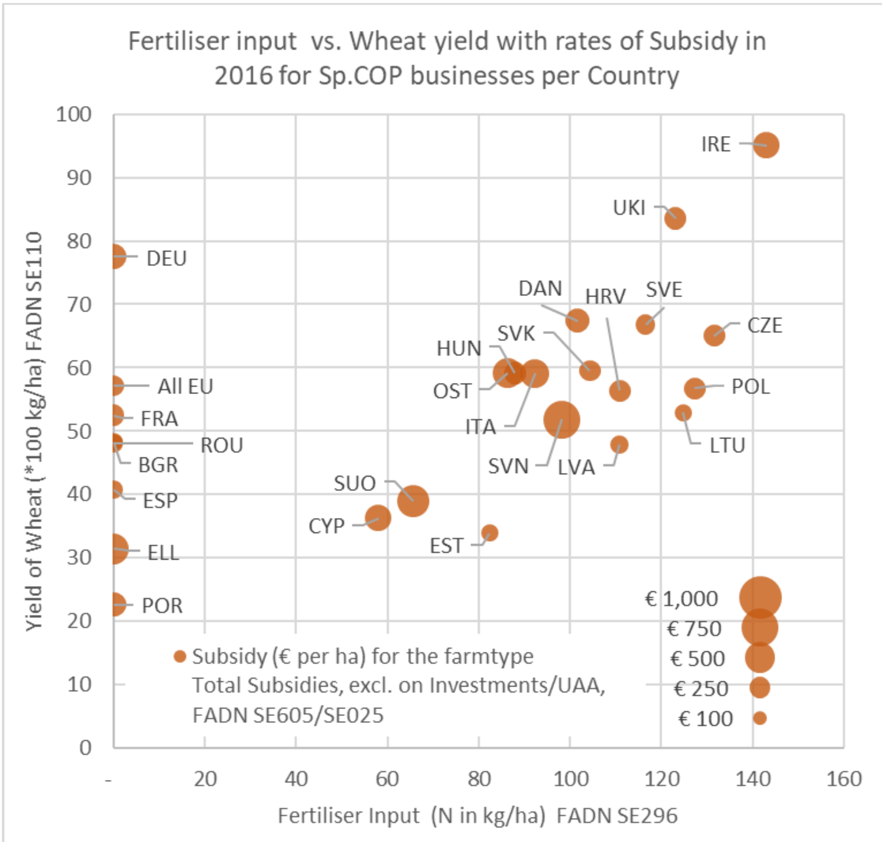

Figure 4: the relationship between input and output intensity for wheat and the average support per ha provided by subsidy for Sp.COP businesses in 2016. Note that markers for countries with wheat yield but no fertiliser inputs rates are included as zero values to allow for some limited interpretation of where they might be likely to fall given the relationships for other countries).

4.3 Production and Supply Systems (extents and intensities of N use and emissions)

Data from Eurostat can be recombined to take a societal-metabolism perspective on competitiveness. For EU member states, this links productivity with the extents and intensities of nitrogen-based fertilisers and nitrogen-related emissions for agricultural production systems. These results begin to tie analysis of competitiveness into the provision, protection or pressure on public goods (such as clean water or a stable climate) set against the need for such systems to deliver food and other agricultural commodities.

The Eurostat agri-environment indicators data provides information at member state level on the intensity of nitrogen inputs to agriculture and the intensity of nitrogen embodied within the outputs (the nitrogen in the harvested crops or later embodied in other outputs such as livestock). The dataset also provides an estimate of the total emissions per member state (though not differentiating between losses directly to air or first to water). The intensities when combined with data on the utilised agricultural area (UAA) generate extents of nitrogen for both inputs and outputs. Both extents and intensities can provide useful insights for agricultural policy making in the context of the nexus.

Figure 5 uses extents of N input (x axis) and outputs (y axis) with the extent of N emissions shown by the marker circles (per member state). This again emphasises the fundamental requirement that if the societal demands or export are to be met there needs to be a production system drawing on resources either locally or via imports. In general, the more productive a member state is in terms of embodied nitrogen in outputs the larger the emissions, though this is not always the case. Compare the UK as an example. It has smaller emissions but with larger embodied nitrogen outputs than Spain, but for similar extent of inputs, the UK is less productive than Germany, but also has smaller emissions.

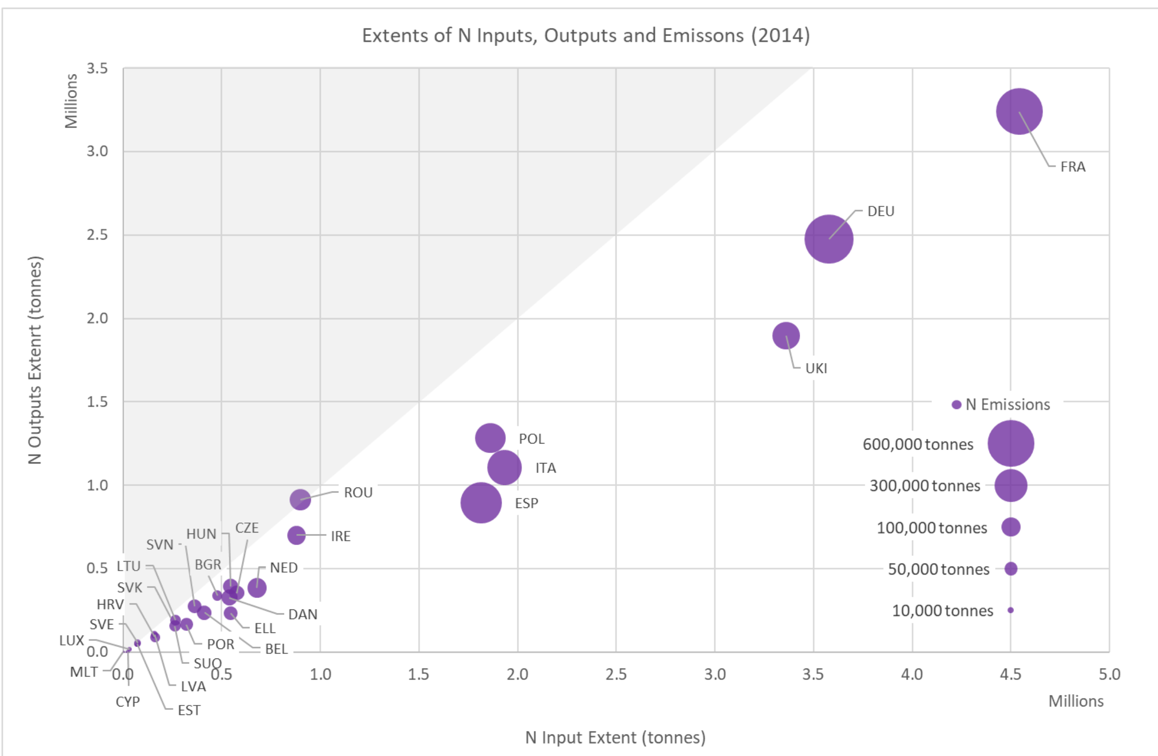

Figure 5: Extent of N Inputs, Outputs and Emissions

The complexity of the societal metabolism of nitrogen in EU agriculture is further emphasised in Figure 6 where the intensity per ha of inputs and outputs are presented with the extent of emissions. Again, there is a significant range of average input intensities (from ~75 kg/ha to ~225 kg/ha, even leaving aside outliers like Netherlands and Belgium) and there are some differences in efficiency (how close to the outputs equals inputs line shown as the grey area to the top left of the chart). In terms of emissions, however, intensity is a poor predictor of the extent of emission (compare Spain, France and Germany, respectively at low, middle and higher input intensities). This is significant for any policy narrative balancing competitiveness and climate change. For climate change mitigation the emission extent is potentially more significant than intensity given there is only one sink for the emissions, the atmosphere. Even if the rates of emissions are low, the cumulative effect of large extents will be extremely problematic. The system may look viable, but it will not be feasible over time given impact on the overall biosphere.

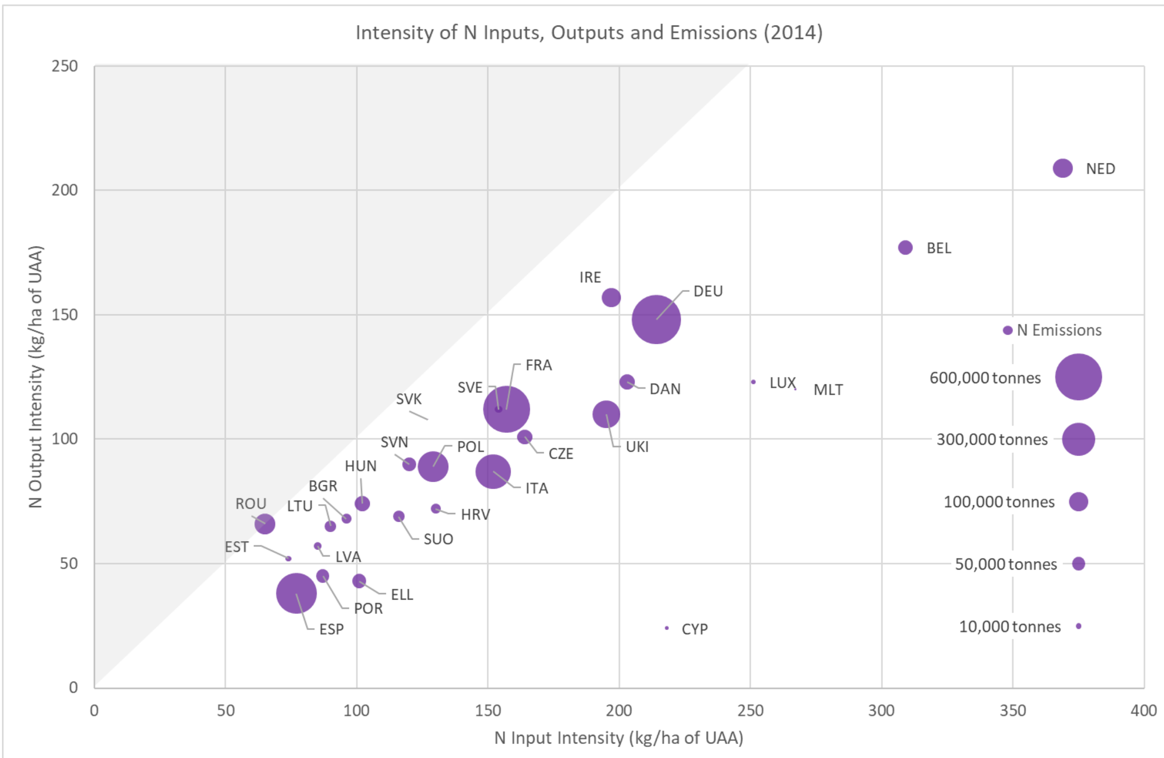

Figure 6: Intensity of N Inputs, Outputs and extent of Emissions

4.4 Production systems impacts – soil erosion

Any policy narrative on EU competitiveness or farm productivity, should be consider these systems draw on natural capital. Soil is a microcosm of the biophysical aspects of the societal metabolism of agricultural production systems. Without the fund of soil there is an existential threat to many of the ecosystem functions and flows of services on which human society depends, not least of which is the ability to provide food and water (Pimentel and Burgess, 2013). Soil is a renewable resource, with rates of soil creation varying geographically depending on climate and lithology, but such rates that are typically low (~0.5 to 1 tonne per hectare per annum). Intensities and extents of soil loss are thus a key indicator of the feasibility (draw on the biosphere) of the EU's production systems. Estimated soil erosion by water is one of the agri-environmental indicators published by Eurostat. This estimate is model based and will not be able to necessarily consider the actual management regimes that are practiced. The actual rates of erosion will depend on the balance of management regimes across production systems.

From the Eurostat estimates the extents and intensities of water-based erosion of soil can be judged (and note that this is missing wind erosion which can also be a significant issue locally). The chart in Figure 7 presents the extent of soil erosion (in tonnes) to highlight member states where there are larger areas subjected to the problem, higher intensities (in tonnes per ha per annum) or both. The markers are scaled using the change in erosion rates from 2000 to 2012 with all but two member-states showing reductions or even substantial reductions (>25%) so the issue of erosion is clearly being taken seriously as an issue.

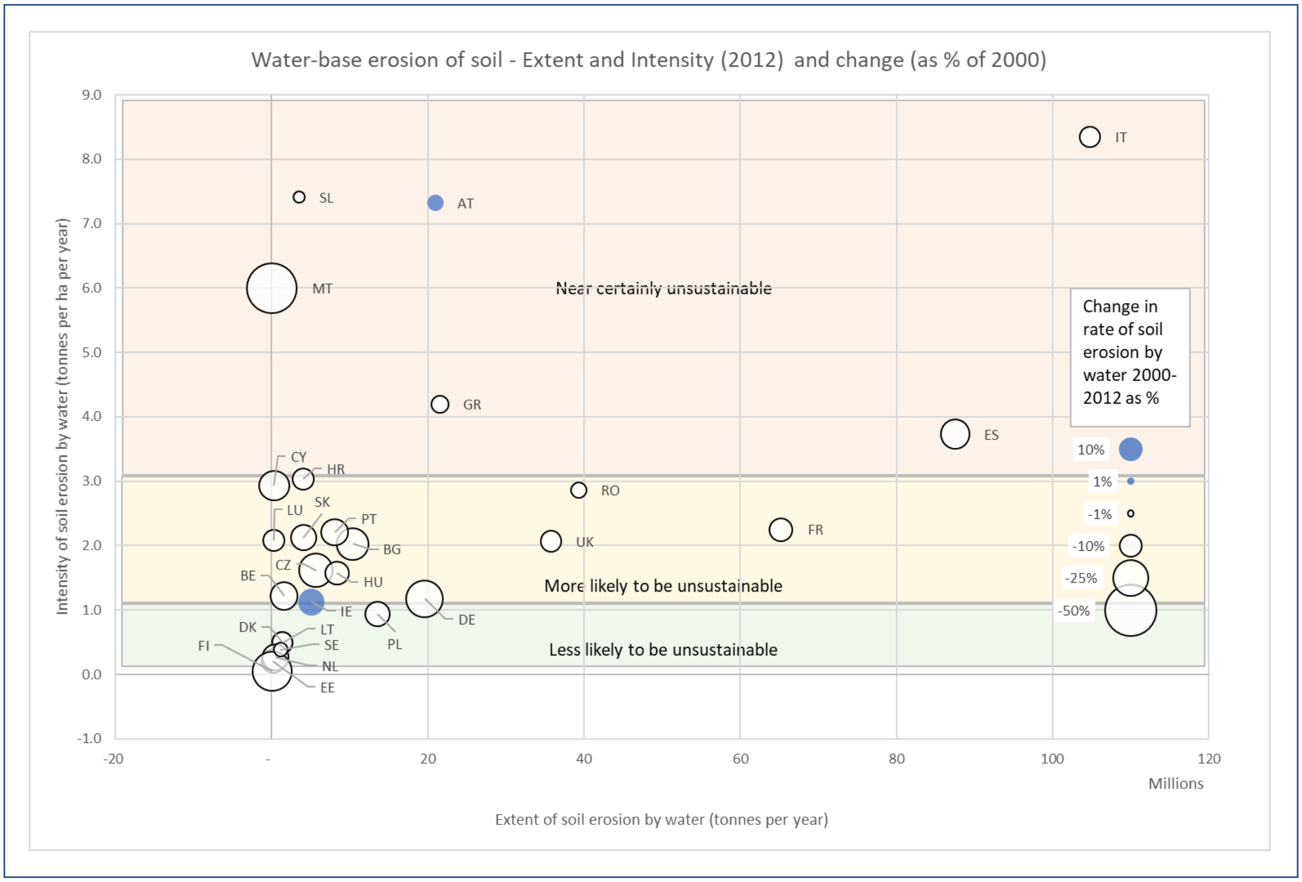

Figure 7: Extent and intensity of soil erosion by water in the EU

Yet despite this progress the rates for most member states remain above thresholds identified by the European Environment Agency (Jones et al., 2012). Above 3.0 t. ha per annum it is near certain that the rate is unsustainable, and even between 1.0 and 3.0 t/ha per annum this likely to be unsustainable – meaning arrangements are not feasible for the biosphere to sustain. Even below the threshold of 1.0 t/ha per annum on average it is likely locally that erosion is damaging the fund of soil. Note that the spatial extents from which this erosion is an average over the cropped areas, so locally soil erosion rates may be much higher than the maximum value shown in the charts. The challenge of soil erosion is also likely to increase, if as seem likely, climate change means more frequent and intense rainfall events in Europe.

5 Discussion of policy relevance and implications

5.1 Trade and competitiveness

The move of the EU from net food importer to exporter over the period since 2007 was argued, by the DG Agri stakeholders who attended the workshop with the project team, as reflecting more market orientation and greater international competitiveness.

The destinations to which these exports are directed, though highlight the contrasting natures of *Societal Demands* being generated at a global level. The rise of a Chinese middle class with changing diet preferences reflects increasing affluence and conventional trading relationships whereas in North Africa the imports play a vital role for food security and in stabilising a politically volatile region close to the EU.

Taking a societal metabolism perspective on the EU's increased exports of agricultural commodities and food, raises a series of interesting questions about how they have been generated. Are the exports the result of additional production, and if so from efficiency gains, intensification or displacement of another activity, or reduced demand inside the EU freeing the outputs for export?

Any import-based increase in production extent comes with a footprint of embodied resources and environmental impacts beyond the borders of the EU that needs to be considered in any assessment of the sustainability of EU agriculture. Given there is concern that EU agriculture is already operating beyond safe environmental limits, then it is possible to question how feasible it is to increase either extent or intensity of production within the EU while reducing environmental loadings and remaining or becoming more competitive within global markets (at least as they operate at present).

In policy terms, CAP support for EU agriculture, makes it competitive and able to respond to changes in global demand (e.g. from China) and to underpin food security in politically volatile regions (e.g. in N. Africa). Yet if the CAP is driving increased use of imports to supply exports, this may conflict with the EU's commitments to the UN SDGs and the Paris Climate Accords by causing deforestation or environmental degradation elsewhere in the world.

5.2 Productivity - wheat in specialist cereal farms

While not a strong relationship, the higher rates of support per hectare are (except for Slovenia), concentrated towards the pareto-front perhaps implying that subsidy is increasing efficiency e.g. through investment in more modern machinery. It should of course be borne in mind that without the extents of wheat production, the significance of the relationships for the EU Supply System can only be hinted by reference to the size of member states.

Despite some apparent opportunities for increases in efficiency of resource use, the magnitude of outputs from farming systems are still tightly coupled to levels of inputs (e.g. fertilisers), which in turn may reduce delivery of public goods (e.g. unpolluted water). Any marked improvement in the provision of public goods from wheat or other similar production systems would seem to require an acceptance of less agricultural outputs within the EU. This suggests that if CAP is to achieve a more sustainable balance of competitiveness and provision of public goods, then a portion of the resources devoted to CAP may be better deployed to reduce the societal demands on the farmed areas of the EU and beyond (e.g. through tackling food waste or transitioning to a more plant-based diet).

5.3 Production systems impacts (nitrogen emissions)

CAP via its funding of measures to deliver the objectives of the Water Framework Directive (WFD) is addressing intensity-based emissions issues, for example water pollution in river basins where the intensity of N use is exceeding buffer capacities for the biosphere. CAP policy may though also need to consider more closely regions where the mixes of production systems have a low per ha intensity but result in overall large extents of emissions. If commitments to the Paris Climate Accords and the Sustainable Development Goals are to be met, then the CAP and other polices may need to support a more fundamental realignment of EU agriculture. Failing to deal decisively with emissions will, however, make it more likely that anthropogenic induced climate change will undermine or destroy the natural capitals on which food security relies.

5.4 Production systems impacts (soil erosion)

The soil erosion analysis suggests a key challenge, since in nearly all member states soil erosion in crop-based production systems is exceeding the rate of soil renewal processes and therefore, existing arrangements are not feasible from a societal metabolism perspective[1]

Given this draw down on the fund of soil, the question becomes one of how far production systems would have to change to be compatible with soil forming rates. Changes involved with reducing soil erosion rates might occur at either

[1] Note of course this is ignoring other factors where soils quality or function is undermined or lost by physical or chemical degradation, or sealing.

the level of individual production steps or entire sequential pathways[2], and might include min-tillage systems or the use of cover crops. This is where CAP implementation efforts e.g. Greening or Agri-Environment schemes and regulations are directed, suggesting the desirability of increased investment in such measures, evaluation of their effectiveness, and revision if needed.

Despite the evident progress being made on soil erosion, a focus on production system solutions alone may not be enough to ensure that they are made compatible with environmental limits. It could be argued that the rates of erosion are so high that there needs to be consideration given to a more fundamental change in the level of output expected from the EU's farmland. In this case, the resources of the EU and member states may need to be deployed to support a transition in Societal Demand to healthier, less wasteful, and ultimately more sustainable patterns of consumption. The difficulties of undertaking such a transition and the complexity and interconnectedness of the policy domains involved are not underestimated by the authors, but the first step would be the acknowledgment that soil erosion is more than an exclusively environmental or even an agricultural concern. Any failure to significantly reduce the rates of soil erosion risks the EU spiralling into a *poverty trap* as described by Holling et al. (2002) with contracting extents of natural resources having to be increasingly intensively exploited in ways that further reduce the extent, quality and/or resilience of the resources.

5.5 Response to the research by policy stakeholders

While this paper doesn't focus on the results of closing the loop of QST with stakeholders, it is worthwhile mentioning that EC policy stakeholders who discussed the societal metabolism analyses were not necessarily convinced by our findings. This reluctance is unsurprising given the unconventional nature of the societal metabolism analysis; and that the results challenge existing policy without providing ready-to-implement solutions.

The response to this feedback is guided by the theories of post-normal science for policy and experience in operating across the science-policy interface in other projects. The project team recognise the legitimate concerns of the policy stakeholders but next phase of analysis in MAGIC still needs to balance being responsive, critical and enabling. Being responsive means better engaging with policy-led deliberative process and providing new or testing existing policy solutions. Being critical means continuing to question the existing framing of issues and governance arrangements, particularly where crucial elements may be being excluded from the policy calculus. For enabling, there is the need for both policy makers and scientists to recognise that more science alone does not provide durable and legitimate solutions to complex,

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[2] These are the lower levels in Figure 1, with sequential pathways referring to alternative complete systems of agricultural management (e.g. suckler cattle) and production steps being alternative steps in in a production process (e.g. grass or cereals based cattle finishing).

wicked and contested issues. This implies on one hand the need for researchers within MAGIC to orient their analysis to be able to take part in existing science-policy-stakeholder processes. On the other hand, salient and credible participation means doing more than operating in responsive mode, delivering solutions to policy-led questions. While this analysis can have considerable instrumental value, particularly in the implementation of policy, a post-normal perspective also implies investing effort in raising awareness of issues, building capacity for analysis beyond the academy, participating in enduring cooperation and perhaps most crucially engendering conceptual change.

Processes of engagement with stakeholders, particularly within the EC DG's remains a priority for the research team, but other stakeholders, such as MEPs or agency staff, have tended to be more open to interactions. This situation may also reflect the challenges for DG staff in terms of capacity versus workload; but may also reflect institutional norms for how interactions with researchers can be conducted as it is rare for DG staff to be involved in discussing preliminary findings and being asked to shape methodological choices. Other stakeholders may have less stake in defending the existing performance of the CAP and, indeed, may have a stake in critiquing the performance for political gain or to leverage more support for their organisational objectives. Further work will consider who is in position to govern and manage the water-environment-food nexus; and who has an interest in promoting change to these governance and management systems; so that the CAP is better able to demonstrate that it is a policy geared to sustainability.

6 Conclusions - bringing it all together

The analyses illustrate tensions between the pursuit of competitiveness and delivery of public goods at different scales (EU and member state) and when analysed from different perspectives (trade, productivity, emissions and impacts). This challenges the claim that CAP is a policy geared towards sustainability and illustrates the difficulties for CAP in balancing the three dimensions of sustainability at present. The strength of a societal metabolism approach is in providing a framework that improves our ability to address these questions from multiple perspectives and scales simultaneously, avoiding false positives that may arise from only looking at part of the system.

The analysis in MAGIC to date is, however, only a work-in-progress. The theoretical perspectives have, however, already generated outputs with potential to stimulate deliberation on important issues around the identity of CAP as a sustainability policy. Furthermore, rather than asking for more data, the analysis shows how it is possible to add value or at least exploit data collection improvements within FADN or EUROSTAT. Yet the formal aspects of the MAGIC QST analysis need to be substantially strengthened. The challenge remains to create instances of the societal metabolism analysis that bring together all the strands together in a more coherent and persuasive manner. In particular, there is the need to demonstrate the formalised use of societal metabolic benchmarks (the Feasibility and Viability analyses) and to be able to do so over time and with flexibility in terms of the metrics/indicators and the focal scales used. Furthermore, there is an aspiration to consider the Desirability (distribution of outcomes, normative judgements of success) of any analysis, given the post-normal framing of the overall project.

There is also potential value in complementing the top-down analysis based on EUROSTAT and FADN data with bottom up analysis exploiting information available on individual production steps and sequential pathways. The intention here is not to focus on the minutia of individual localised systems but to try to bridge between lower levels where the technical coefficients of individual production steps or sequences of steps are well characterised, and the aggregate outcomes that emerge at the regional or member state levels. Bridging this meso-scale means inferring the extents, intensities and mixes of sequential pathways that make up production systems and how these are supplemented using imported resources. Such analysis is crucial to understanding the outcomes of policies necessarily enacted at supra-national or member state level but whose impact play out via complex adaptations at any, and all, of the system scales identify in this paper.

The QST process suggests the need to question policy narratives within the CAP that would prioritise growth over facilitating a sustainability transition. A transition to sustainability requires analyses that focus on what underpins our systems of production and makes space for deliberation on systems-based solutions. Our analysis suggests that it will be challenging to make marked progress for the existing stated CAP objectives and the ambitious objectives suggested for CAP post 2020. It may be better to acknowledge and deliberate on the limits of CAP and acknowledge the difficult trade-offs, rather than accepting a justification of CAP that is unlikely to be delivered, thereby undermining its credibility and legitimacy.

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