Report on the Monitoring Tools to Improve the Traceability of Climate Action in the European Farming Sector

Synthesis report

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Executive summary

Climate smart agriculture (CSA) aims to combine the objectives of agricultural systems to support food security and provision of biomass for the bio-based products with responding to the need for climate adaptation and utilizing the potential for mitigation. Climate smart agriculture can be implemented through a broad portfolio of measures that can imply a change of farm management, a change of land use and the adoption of new technologies.

This study first made an inventory of available databases and indicators that might aid quantification and monitoring of CSA practice implementation and outcomes. After identifying 41 CSA measures, EU level and country level databases were scanned for data that might serve as indicators for these measures. The inventory demonstrated that indicators were available for almost all CSA measures. Data were lacking for among others feed management, cultivar selection, and precision farming. However, despite the data availability, most of the identified data does not allow for farm-level monitoring due to a long revisit time or an insufficient spatial or thematic resolution.

Next, the study investigated which farm carbon calculation tools might be suitable to quantify, on both a farm and a European level, greenhouse gas balances in the broadest sense. Based on a literature review, an initial set of tools was identified. The set of tools was narrowed down by comparing data requirements to data availability at a European scale, leaving 4 tools that were more deeply explored. Four tools (Ex-Ante Carbon balance Tool (EX-ACT), Carbon Calculator to promote Low-Carbon Farming practices (LC-Farm), the Farm Carbon Calculator (FCC), and SOSTARE) were tested deeper by acquiring the data needed to calculate farm greenhouse gas balances at European level. This exploration demonstrated that all tools suffer from considerable data gaps to an extent that strongly limits their applicability. Therefore, an alternative, data-driven approach of quantifying climate smart agriculture was applied. Using FADN and LUCAS data, the percentage of farms that adopted a set of measures was quantified. This enabled to quantify the uptake of a limited set of measures, demonstrating that while over 80% of European farms have one or more CSA practices in place, comparison between farms within the same country and ecoregion indicates a significant potential for increased adoption of CSA measures in the EU agricultural sector. For instance, only 5% of land-based farms (i.e. farms with cropland or grassland as opposed to factory farms) grow catch crops according to the FADN classification. The use of permanent grasslands on the other hand is relatively widespread, with 66% of the farms that could potentially implement the measure actually doing so. A potential rate of additional CSA uptake can, conceptually, be calculated as well, but this requires setting a benchmark for the maximum uptake level.

Since the adoption of CSA practices might (initially) imply higher costs for farmers, a certification scheme labelling low-carbon food products allowing for price differentiation might guide sustainable consumer choices and thereby incentivize farmers to convert to CSA practices. Drawing from a review of existing food and non-food carbon labels, as well as existing EU certification initiatives and scientific literature, the study explored potential synergies or conflicts with existing EU certification initiatives, and assessed factors driving the costs and benefits associated with six policy options for the development of a "climate smart agriculture" certification scheme, including their certification requirements, scope, monitoring methodologies and communication to consumers:

1. Integrating **input**[1] and **output**[2]-based CSA criteria into the **EU Ecolabel** (i.e. an EU Ecolabel for farming products)
2. Integrating **input**-based CSA criteria into the **EU Organic label** (i.e. update the organic standards with more climate-oriented requirements)
3. Integrating **input**-based CSA criteria in the **EU Organic label** as **add-on** (i.e. an optional additional certification scheme for organic farmers who aim to adopt CSA practices)
4. Developing a **new input**-based CSA labelling scheme (i.e. a "climate only" low-carbon farming certification scheme)
5. Developing a **new output**-based CSA labelling scheme (i.e. a Product Carbon Footprint for farmed products)
6. Developing **a new hybrid** CSA labelling scheme (i.e. a labelling scheme setting **input-based** criteria and measuring **output**)

Certification schemes need to balance two main trade-offs, between environmental ambition and feasibility of the certification requirements, and between credibility and administrative burden. Therefore, an ideal label is a credible label that reduces emissions within reasonable compliance and administrative costs.

Among the policy options assessed, the option proving most promising in terms of balancing feasibility and ambition is the hybrid approach (option 6). The options highlighting potential reductions of administrative burden include the new CSA label relying on input-based criteria (option 4), and the integration of CSA criteria into the EU Organic label (options 2 and 3).

All certification schemes risk to be confronted with the consequences of consumer confusion due to the proliferation of environmental labels, which would need to be countered by clear communication on both the purpose and benefit of the scheme, as well as the climate impact of food in general.

[1] Input or best-practice based criterion: criterion that explicitly prescribes the measures manufacturers have to adopt or ban in order to be certified.

[2] Output- or result- based criterion: criterion that explicitly set thresholds on measurable environmental outputs such as GHG emissions, without specifying how these limits should be respected.

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Abstract

Climate smart agriculture (CSA) aims to combine the objectives of agricultural systems to support food security with responding to the need for climate adaptation and utilizing the potential for mitigation. This study aims to build and test a monitoring tool for climate smart agriculture in the European farming sector and to explore options for a certification scheme for labelling goods produced under such conditions.

A review and test of carbon calculation tools for quantifying GHG balances on both farm and European level demonstrated that all tools suffer from considerable data gaps. An alternative data-driven approach quantified the uptake of CSA measures across the EU. The analysis demonstrated that while over 80% of European farms have one or more CSA practice in place, comparison between farms within the same country and ecoregion indicates a significant potential for increased adoption of CSA measures.

Drawing from a review of existing food and non-food carbon labels, existing EU certification initiatives and scientific literature, the study assesses factors driving the costs and benefits associated with six policy options for the development of a “climate smart agriculture” certification scheme to foster the adoption of CSA measures. It was found that effective and efficient labelling schemes balance two main trade-offs, between environmental ambition and feasibility of the certification requirements, and between credibility and administrative burden. Clear communication on both the purpose and benefit of the scheme, as well as the climate impact of food, would be needed to avoid consumer confusion.

Résumé

L'agriculture intelligente face au climat (AIC) vise à combiner les objectifs des systèmes agricoles pour soutenir la sécurité alimentaire en répondant au besoin d'adaptation climatique et en utilisant le potentiel d'atténuation. Cette étude vise à créer et à tester un outil de surveillance de l'agriculture intelligente face au climat dans le secteur agricole européen et à explorer les options d'un schéma de certification pour l'étiquetage des marchandises produites dans ces conditions.

Un examen et un test des outils de calcul des émissions carbones pour quantifier les bilans de GES tant au niveau des exploitations agricoles qu’au niveau européen ont montré que tous les outils disponibles présentaient des lacunes considérables en termes de données. Une approche alternative a quantifié l'adoption des mesures AIC dans l'ensemble de l'UE. L'analyse a montré que, alors que plus de 80% des exploitations européennes appliquent une ou plusieurs pratiques AIC, la comparaison entre les exploitations d'un même pays et d'une écorégion indique un fort potentiel d’accroissement de l’adoption des mesures AIC.

En s’appuyant sur un examen des « labels carbone » alimentaires et non alimentaires, sur des initiatives de certification de l’UE et sur la littérature scientifique existantes, l'étude a évalué les facteurs déterminants des coûts et bénéfices associés aux six options politiques pour le développement d'un système de certification AIC destiné à encourager l'adoption de mesures AIC. Il a été constaté que des systèmes d'étiquetage efficaces et efficients équilibrent deux compromis principaux, entre ambition environnementale et faisabilité des exigences de certification d’une part, crédibilité et charge administrative d’autre part. Une communication claire sur l'objectif et les avantages du système, ainsi que sur l'impact climatique des aliments, serait cependant nécessaire pour éviter la confusion chez les consommateurs.

Zusammenfassung

„Klimasmarte Landwirtschaft“ (eng.: *Climate Smart Agriculture*, CSA) ist ein Konzept, welches anstrebt, die Ziele der Agrarwirtschaft, i.e. Unterstützung der Ernährungssicherheit, mit Maßnahmen zu verbinden, welche die Notwendigkeit zu Klimawandelanpassung adressieren und Potentiale des Klimaschutzes nutzen. Diese Studie zielt darauf ab, ein Monitoringinstrument für CSA im europäischen Agrarsektor zu entwickeln und zu testen sowie Optionen für ein Zertifizierungssystem für die Kennzeichnung von unter solchen Bedingungen hergestellten Waren zu untersuchen.

Eine Überprüfung und Test von Kohlenstoffrechnen zur Quantifizierung der THG-Bilanz auf agrarbetrieblicher und europäischer Ebene haben gezeigt, dass alle solche Instrumente mit erhebliche Datenlücken zu kämpfen haben. Ein alternativer, datenbasierter Ansatz quantifiziert in der Studie die Anwendung von CSA-Maßnahmen in der gesamten EU. Die Analyse ergab, dass, obwohl bereits mehr als 80% der europäischen landwirtschaftlichen Betriebe eine oder mehrere CSA-Praktiken anwenden, ein Vergleich zwischen Betrieben innerhalb desselben Landes und der Ökoregion auf ein erhebliches Potenzial für eine verstärkte Einführung von CSA-Maßnahmen hinweist.

Basierend auf einer Überprüfung bestehender Zertifikate zu Kohlenstoffausstoß (Lebensmittel- und Nichtlebensmittel), bestehender EU-Zertifizierungsinitiativen und wissenschaftlicher Literatur untersucht die Studie Faktoren, welche die Kosten und den Nutzen von sechs politischen Optionen für die Entwicklung eines Zertifizierungssystems für klimasmarte Landwirtschaft beeinflussen, um die Aufnahme von CSA-Maßnahmen zu unterstützen. Die Studie stellt fest, dass für effektive und effiziente Zertifizierungssysteme zwei wesentliche Kompromisse – zwischen ökologischem Anspruch und Durchführbarkeit der Zertifizierungsanforderungen sowie zwischen Glaubwürdigkeit und Verwaltungsaufwand – abgewogen werden müssen. In diesem Zusammen ist eine klare Kommunikation über Zweck und Nutzen solcher Zertifizierungsmaßnahmen sowie über die Klimawirkung von Lebensmitteln erforderlich, um Verwirrung bei den Verbrauchern zu vermeiden.

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Introduction

Covering half of the EU-28's surface, the EU agricultural sector is currently responsible for 10% of EU wide anthropogenic greenhouse gas (GHG) emissions[3]. Between 1990 and 2012, agricultural emissions decreased by over 20%, mainly through reductions of CH_4 (ruminants' digestive processes) and N_2O (use of fertilizer) emissions. In terms of non-CO2 emissions, the agricultural sector currently accounts for 47.5% and 72.2% of total EU CH_4 and N_2O emissions respectively. In 2013 agricultural emissions, mainly CH_4, increased slightly after which they have stabilized during the last years. Land use and forestry activities (the so called LULUCF sector, acronym for Land Use, Land Use Change and Forestry) sequester 6.8% of EU anthropogenic GHG emissions.

As defined by the Food and Agricultural organisation of the United Nations the concept of climate smart agriculture (CSA) points to the attempt to sustainably increase food security while building resilience and adapting to climate change and utilizing the potential for mitigation[4]. A broad range of measures can be identified as implementing Climate smart agriculture which either imply a change of farm management or a change of land use.

This report is the result of the project "Monitoring tools to improve the traceability of climate action in the European farming sector". The objective of the study is to build and test a monitoring tool for climate smart agriculture in the European farming sector and to explore options for a certification scheme for labelling goods produced under such conditions.

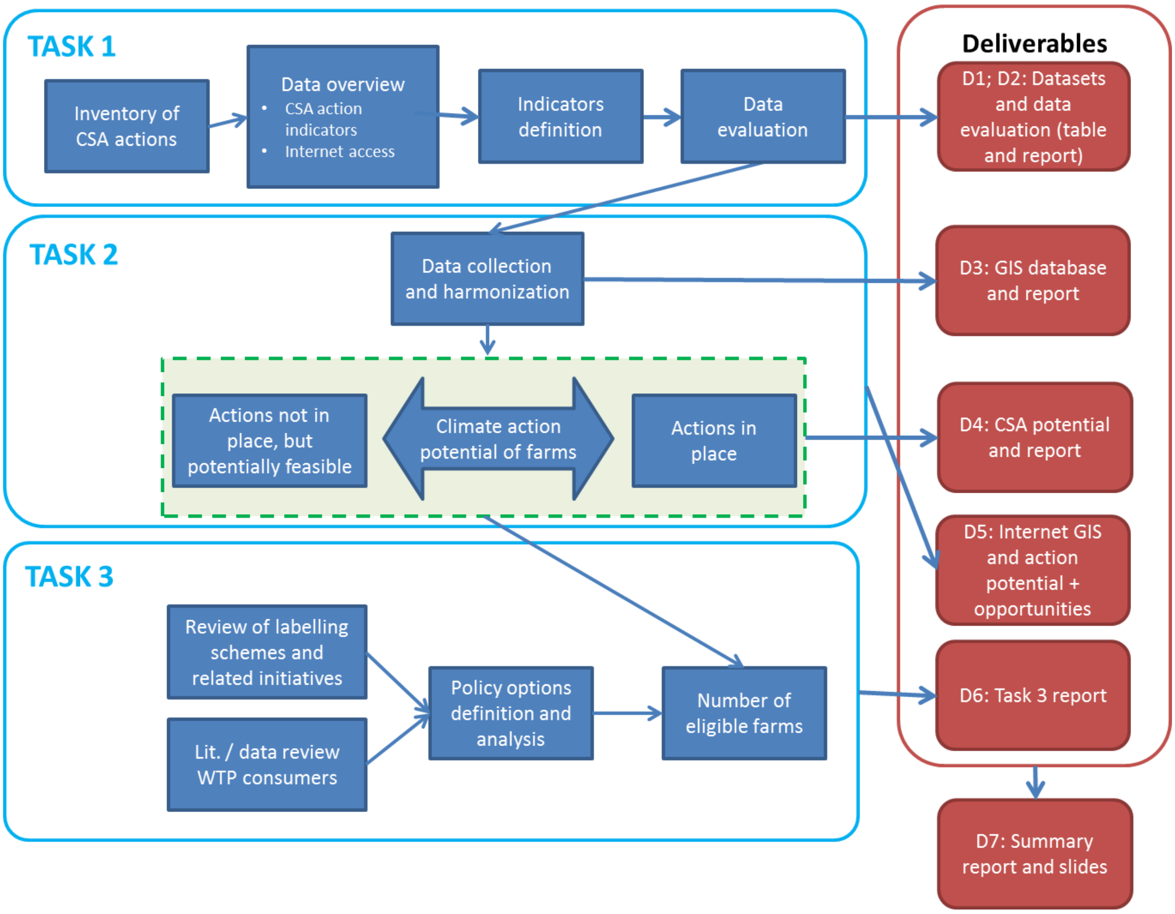
Concretely, the study was composed of three Tasks presented in Figure 1 below.

Task 1 identified currently available and future data sets useful for monitoring climate smart agriculture in Europe. Task 2 build a demonstrator for monitoring using a Geographical Information System (GIS) and location-based techniques and Task 3 explored and assessed multiple policy options for the design of a climate smart agriculture certification scheme label to potentially incentivize farmers for taking up actions against GHG emissions.

[3] European Environmental Agency (EEA). Annual European Union greenhouse gas inventory 1990 – 2016. EEA Report No 5/2018

[4] FAO, 2010: "Climate-Smart" Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation.

Figure 1 - Study methodology



1. Task 1: Overview and inventory of existing data sets

1.1 Introduction

Task 1 sets the data basis for the remaining tasks of the study. This section identifies data that might be suitable for monitoring Climate Smart Agriculture (CSA) at different scales and provides recommendations for data collection and monitoring.

Primary goal of Task 1 is to identify suitable data, but this cannot be done without clarifying the scope of CSA measures that need to be monitored or without considering calculation tools for the effects of CSA. Therefore, CSA measures are listed and classified according to data needs for monitoring (section 1.3). Databases are reviewed and evaluated for their applicability for CSA monitoring (section 1.4) and existing tools for calculating the effects of CSA measures in terms of GHG emissions are evaluated (section 1.4). This leads to conclusions and recommendations on appropriate tools at European scale and for a case study in the Netherlands (section 1.5).

1.2 Methods

As a first step, CSA measures are listed and evaluated for data needs. The list of measures provided in the Terms of Reference is used as a basis and cross checked with a recent review of sustainable intensification measures (Weltin et al., 2018[5]) that identified the overlap between SI measures and CSA measures, and a recent review on CSA measures (Scherer and Verburg 2018[6]). Weltin et al. (2018) searched for "sustainable intensification" in title, keywords and abstract through Scopus and Web of Science. They identified 349 papers in which 26 SI measures were identified. From these, 22 measures also aim at climate change mitigation / adaptation and can, therefore, be seen as CSA measures. Scherer and Verburg (2018) reviewed literature with "climate smart agriculture" in title, keywords, and abstract and identified 20 CSA measures. Literature underlying these review papers was checked when necessary to attempt to quantify the CSA measures.

All measures are briefly described, including their trade-offs and synergies with other measures. The measures are classified as aiming at mitigation, adaptation or both; as reducing emissions or enhancing sinks or offsetting fossil fuel use; according to their scale of implementation, and for their relevance to different farming systems.

Secondly, data potentially suitable for the quantification of uptake or effects of CSA measures are inventoried and reviewed. European scale data and national scale data for the Netherlands is explored through repositories for spatial and statistical data.

The data exploration identifies specific *data repositories / databases* and *datasets* that can provide *indicators* for CSA. Many of the databases identified contain one or just a few relevant datasets; a few of the databases contain a long list of relevant datasets. For each dataset, a list of characteristics is presented:

- Link to the dataset;
- Brief description;

[5] Weltin, et al. 2018: Conceptualising Fields of Action for Sustainable Intensification – A Systematic Literature Review and Application to Regional Case Studies. Agriculture, Ecosystems & Environment 257: 68-80.

[6] Scherer, L.A., and P.H. Verburg, 2018: Mapping and linking supply- and demand-side measures in climate smart agriculture, Agronomy for Sustainable Development 37:66.

- Type of data: statistics, spatial point / polygon / raster data;
- Spatial resolution (detail) and extent (coverage);
- Thematic resolution: brief technical description of data contents, including classification details such as number of classes or thematic accuracy;
- Temporal resolution (revisit time) and extent (timeframe);
- A linkage to CSA monitoring is made through:
  - Indicating the CSA measure that the dataset can monitor;
  - Indicating if the dataset can serve as activity data or emission factor, further specified by activity that can be measured with the dataset. This only applies to datasets that can be used to measure effects of CSA measures in terms of GHG emissions.
- Quality issues of the data, consistent with standard GIS quality elements and INSPIRE specification for the specific data type;
- Data access possibilities and restrictions are described;
- Possibilities for correction are evaluated.

Third, carbon calculator tools are evaluated. Carbon calculators are tools that calculate a carbon footprint of, typically, a person, a business in general, or a farm. A google search for “farm carbon calculator” yielded 815 hits with many doubles, from which a series of carbon calculators applicable to farms was selected. Alternative search terms such as “farm carbon cutting tools” resulted in very similar outputs. Tools suggested by the EC were also included. The carbon calculators are briefly described. This includes the system boundaries and scale, the applicability to farming systems, and the possibilities to calculate the effects of CSA measures.

1.3 CSA measures

1.3.1 Introduction

GHG emissions from Agriculture, Forestry and Other Land Use (AFOLU) originate mostly from agriculture, through cultivation of crops and livestock, and related land use change, most prominently deforestation. Nitrous oxide (N_2O) emissions from agricultural soils increased by 30.9% between 1990 and 2012 which corresponds to 39.8% of total agricultural emissions (FAO, 2015). This is mainly due to increase in crop production and fertilizer use as well as other nitrogen sources such as crop residues (US-EPA, 2012). The livestock sector contributes an estimated 7,100 million tonnes of CO_2 equivalent per year, representing 14.5% of human-induced GHG emissions (Gerber et al., 2013). Cattle and other ruminants are responsible for the vast majority of livestock emissions and account for over 60% of all direct agricultural emissions. Feed production and processing as well as enteric fermentation from ruminants are the two main sources of emissions. Land use and land-use changes for feed production and pastures accounting for approximately 1.6 $GtCO_2$-eq per year (Gerber et al., 2013). CH_4 emissions from enteric fermentation increased by 11.2% from 1990 to 2012, from 1,869 $MtCO_2$-eq to 2,080 $MtCO_2$-eq, a share that represents 38.7% of total agriculture emissions in 2012 (FAO, 2015). One of the major causes of deforestation is the expansion of agricultural lands (Gibbs et al., 2010). From 1970 to 2010, the global area of agricultural land (including arable land, permanent crops, permanent meadows and pastures) has increased by 330 million hectares (Taheripour et al., 2013).

AFOLU emissions are partly counterbalanced by sequestration of carbon in soil and biomass.

Climate change has direct and indirect negative effects on agriculture. Extreme weather events like drought, increased mean temperatures and increased rainfall patterns negatively affect the growth rates of yields for most crops and the indirect effect of heat stress has increased vulnerability of livestock to diseases, reduced fertility and reduced milk production.

CSA aims to combine the objectives of agricultural systems to produce food and non-food biomass with responding to the need for adaptation set by the climate change impacts, and by utilizing the potential for mitigation (FAO, 2010[7]). Climate smart agriculture identifies trade-offs and synergies among production, adaptation, and mitigation, and utilizes these to inform development of sustainable agricultural strategies (Lipper et al., 2014[8]). As such, CSA is closely related to sustainable intensification, by the simultaneous focus on enhancing or maintaining agricultural production while reducing environmental impacts. Implementation and effectiveness of CSA depends on a complex interaction of locally dependent variables, setting a need for context dependent funding to support implementation.

Climate smart agriculture can be implemented through a broad portfolio of measures that, similar to sustainable intensification, can imply a change of farm management or a change of land use allocation. Measures can be implemented and have effects at different scales; from farm to region (Weltin et al., 2018) and beyond. While CSA is a multifunctional concept that aims to address multiple challenges simultaneously, in practice, implementation tends to focus mainly on either mitigating climate change or adaptation, with stable production as a boundary condition rather than a main goal. CSA measures can be subdivided into generic measures that are potentially feasible at all farms throughout the EU territory; sector specific measures that only apply to specific farming systems (e.g. livestock or arable farms); and location specific measures that only apply under specific biophysical or topographic conditions.

Mitigation measures can target (1) reducing emissions from agriculture; or (2) enhancing sinks (Smith et al., 2008[9]).

Generic measures to reduce emissions include among others technical measures like reducing fuel or energy use by implementing more efficient equipment or installing solar panels. Sector specific emission reduction measures include optimizing livestock feeding practices to reduce CH_4 emissions, improving water management in rice production to reduce GHG emission, or the adoption of conservation tillage to reduce CO_2 emission. Location specific measures that reduce emissions include for example measures to avoid drainage of peat soils.

Sink enhancement methods aim at optimizing the capacity of the soil to sequester greenhouse gases. The effectiveness of carbon sinks depends on the capacity for carbon storage, which depend on climate conditions (West et al. 2010[10]) and soil conditions.

[7] Lipper et al. 2010: "Climate smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation, Food and Agriculture Organisation.

[8] Lipper et al. 2014: Climate smart agriculture for food security, Nature Climate Change 4: 1068-1072. doi: 10.1038/nclimate2437.

[9] Smith et al. 2008: Greenhouse gas mitigation in agriculture, Philos Trans R Soc Lond B Biol Sci 363: 789-813. doi: 10.1098/rstb.2007.2184. https://www.ncbi.nlm.nih.gov/pubmed/17827109.

[10] West et al. 2010: Trading carbon for food: Global comparison of carbon stocks vs. crop yields on agricultural land, PNAS 107(46):19645–19648. doi: 10.1073/pnas.1011078107.

Enhancing carbon sinks on a landscape or larger scale can be achieved through land sparing, i.e. increasing agricultural yields to spare land for natural habitat restoration (Lamb et al. 2016[11]). At a farm level, carbon sequestration can be increased for instance by agroforestry. Large agricultural areas are suitable for this practice (Ramachandran Nair et al. 2009[12]). Its potential for carbon sequestration depends on site characteristics, management practices, and the tree species (Ramachandran Nair et al. 2009). Crop residues and animal manure added to soils can also increase soil organic carbon if the soil is not saturated. However, its benefits depend on the alternative fate of the biowaste (Powlson et al. 2011[13]). When transforming biowaste into biochar with more stable carbon, renewable energy is additionally produced and can offset fossil energy (Woolf et al. 2010[14]). The sequestration potential of grasslands can be increased by optimizing grazing intensities, increasing the pasture productivity, and introducing new grass species (O'Mara 2012[15]; Scherer and Verburg, 2018).

Adaptation measures include technological advances on crop responses to abiotic stress, and optimization of irrigation strategies. Also, climate adaptation can be achieved through agronomic changes such as changing the timing of crop growth or switching to crops that are more resistant to water or temperature stress. Finally, income diversification and insurances can enhance farmers' adaptive capacity (Weltin et al., 2017; Linnerooth-Bayer et al., 2014[16]).

1.3.2 Monitoring needs

CSA measures can be evaluated by assessing the implementation level or by assessing the effects in terms of emission reduction, sink enhancement, or impact reduction. For assessing the implementation level, data is required that indicates if a farm has implemented the level or not (binary), or the area on which a measure is implemented. When the effects of measures are to be assessed, GHG emission or sequestration needs to be measured or calculated. Approaches for GHG emission calculation range from Tier 1 to Tier 3, where emissions are quantified using universal emission factors (Tier 1), country specific emission factors (Tier 2), or process modelling based approaches (Tier 3). Emission factors, also for soil carbon sequestration, originate from emission measurements and from long-term field studies. Effects of CSA measures on soil carbon need to be evaluated in such an indirect way because of uncertainties and measurement errors inherent to measuring changes in soil carbon stocks. CSA measures can sequester up to 2 tonnes C / ha per year, while soil organic carbon stocks are considerably larger and strongly variable over short distances. Hence, directly measuring effects of CSA in terms of soil organic carbon stock increases is challenging.

Soil organic carbon stocks in European agricultural land are estimated at 17.63 Gt C. Low carbon stocks are common in arable land in Southern Europe, while also intensively managed agricultural land in more northern countries have low soil organic carbon stocks.

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[11] Lamb et al. 2016: The potential for land sparing to offset greenhouse gas emissions from agriculture, Nat Clim Chang 6(5):488–492.

[12] Nair et al. 2009: "Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal", Environmental Science & Policy 12.8: 1099-1111.

[13] Powlson et al. 2011: Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false, Eur J Soil Sci 62(1):42–55. doi: 10.1111/j.1365-2389.2010.01342

[14] Woolf et al. 2010: Sustainable biochar to mitigate global climate change, Nat Commun 1:56.

[15] O'Mara 2012: The role of grasslands in food security and climate change, Ann Bot 110(6):1263–1270. https://doi.org/10.1093/aob/ mcs209

[16] Linnerooth-Bayer et al. 2014: Financial instruments for disaster risk management and climate change adaptation, Climatic Change 133: 85-100. doi: 10.1007/s10584-013-1035-6.

Separated by main land use types, stocks vary between x and y in grassland, a and b in cropland, and c and d in permanent crops. Emission or sequestration are influenced by the balance between carbon input quantity and quality on the one hand, and mineralization on the other hand. As mineralization increases upon drier and warmer conditions, carbon emissions from arable land tend to be higher in southern Europe, as long as carbon stocks allow. In grasslands, inputs from particularly root biomass are high and mineralization is limited when lands are not ploughed, resulting in carbon balances between 4.5 g C/m^2 in Portugal and 40.1 g C/m^2 sequestration in Switzerland[17]. Harvesting and tillage in cropland result in lower input and higher mineralization, resulting in emissions that vary between 2.2 and 60.8 g C/m^2.

The scope of CSA measures defines what data is needed for monitoring. Activity data for several measures that affect land cover could be monitored through remote sensing, although achieving a sufficient thematic detail is still challenging. while Measures that affect the farm structure require farm level statistics. The effect size of measures is important to evaluate the relevance to climate change mitigation or adaptation, although also small contributions to climate change mitigation or adaptation that are widely applicable are relevant. The focus on reducing emissions versus enhancing sinks versus offsetting fossil fuel emissions set requirements for the temporal extent and resolution of monitoring. While sink enhancement measures have a slower, longer-lasting effect and therefore require longer-term monitoring, several of the emission reduction measures can have immediate effects and therefore require a high temporal resolution.

1.3.3 CSA measure description and classification

Table 1 below lists measures that are identified as climate smart agriculture measures. For each measure, if available from a literature inventory, the reduction potential is given. Unless indicated otherwise, this is quantified as the percentage GHG emission reduction relative to the total agricultural GHG emission (CO_2, CH_4, and N_2O, in CO_2-equivalents) in the EU upon full implementation of the measure. Next, the table indicates if the measure aims at reducing emissions, at enhancing sinks, or offsetting fossil fuel emissions. The table distinguishes to which production system the measure applies. Linking measures to production systems is necessary to calculate the potential number of farms that can apply a specific measure and requires a classification of production systems into five classes. We distinguish between:

- Arable crop production systems: can implement measures that affect emission / sequestration from arable crops or land;
- Land bound systems; these include land bound crop production as well as land bound livestock systems. These systems can implement measures that imply changes in land cover or land use;
- Livestock systems, either land bound or industrial. Livestock systems can implement measures that aim to reduce livestock emissions. Industrial livestock systems cannot implement measures that imply changes in land cover / land use;
- Generic; applicable to all farming / production systems; and
- Permanent crops: measures that imply changes in / adoption of permanent crops tend to be difficult to implement for farms without any permanent crops.

[17] Janssens, I. A., et al. (2005). "The carbon budget of terrestrial ecosystems at country-scale–a European case study." Biogeosciences **2**: 15-26.

Next, the scale at which the measure applies is specified. CSA measures generally are applied at farm scale. However, some of the measures identified benefit from regional cooperation or coordination. In addition, it is indicated if the measures are land related or related to the farm structure and finally briefly evaluation limitations, and trade-offs and synergies with other CSA measures.

Table 1: Overview of CSA measures

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Reduced tillage	Aims to reduce soil organic carbon decomposition	<0.15 ton C/ha per year (Lugato et al. 2014[18]); 0.0059 to 0.0180 t CO2e /ha/y (Martineau et al., 2016[19])	R, E,F	M, A	Crop	Farm	Land	SOC effect might be limited	Enhances water retention
Use of cover crops	Primarily serve to increase soil fertility through SOC sequestration and N fixation	43%; 0.88 to 1.47 t CO2e /ha/y[16])	E	M, A	Land-based	Farm	Land		Also reduce runoff and erosion
Use of catch crops	Primarily aim to reduce runoff and erosion	0.88 to 1.47 t CO2e /ha/y[16])	E	A	Land-based	Farm	Land		Also serve to increase SOC if the right crop is chosen
Perennial grasses	Reduces SOC decomposition.	0.3-0.4 ton C/ha per year (Soussana et al. 2004[20])	E	M	Land-based	Farm	Land		Improve soil structure.

[18] Lugato et al. 2014: Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices. Global Change Biology 20, 3557–3567, doi: 10.1111/gcb.12551.

[19] Martineau et al. 2016: Effective performance of tools for climate action policy - meta-review of Common Agricultural Policy (CAP) mainstreaming. Report for European Commission - DG Climate Action,

[20] Soussana, J. F., et al. (2004). "Carbon cycling and sequestration opportunities in temperate grasslands." Soil Use and Management 20(2): 219-230.

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Permanent crops	Reduces SOC decomposition, increases biomass C sequestration	0-0.6 ton C/ha per year (Smith et al. 2005[21])	E						
Bioenergy crops	Might contribute to SOC enhancement might offset fossil fuel use.	Huge range of CO_2 emission / sequestration reported.	E, F						
Deep rooting crops	Enhance SOC sequestration	0-0.6 ton C/ha per year (Smith et al. 2005)	E						
Management of crop residues	Usage of crop residues as compost or transform into biochar	0.1-0.7 ton C/ha per year (Smith et al. 2005)	R, E	M	Crop production	Farm	Both	Can trade-off with alternative use of crop residues	Biowaste to biochar transformation can produce renewable energy

[21] Smith, P., et al. (2005). "Carbon sequestration potential in European croplands has been overestimated." Global Change Biology 11(12): 2153-2163

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Agro-forestry	Simultaneous production of field crops and tree crops	79% (Scherer and Verburg, 2018); 0.15-0.88 ton CO_2e/ha per year (Martineau et al. 2016); 0.48 ton C/ha per year (Palma et al. 2007[22])	E	M	Crop production ; permanent crops	Farm	Both	Requires a considerable farm system change	Implies uptake of several other land related measures
Zero tillage	Aims to reduce soil organic carbon decomposition; could reduce energy use	0-0.4 ton C/ha per year (Smith et al. 2005);	RE	M	Crop production	Farm	Both	Can lead to increased weed pressure. SOC effect might be limited	Enhances water retention
Aff-/Ref-orestation / Woodland planting	Carbon sequestration in biomass and soil	0.3-0.5 ton C/ha per year (Smith et al. 2005); 1.47-1.83 ton C/ha per year (Martineau et al. 2016)	E	M	Land-based	Farm; region	Both	Trade-off with land available for production, so with food security.	Enhances water retention, can yield biofuel
Woodland management	Thinning or other management strategies influence soil and biomass carbon sequestration	0.37 ton C/ha per year (Martineau et al. 2016)	E	M	Land-based	Farm; region	Land		Can enhance water retention, can yield biofuel

[22] Palma, J. H. N., et al. (2007). "Modeling environmental benefits of silvoarable agroforestry in Europe." Agriculture, Ecosystems & Environment 119(3-4): 320-334

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Preventing deforestation ; land sparing	Intensifying to enable production on a smaller area, leaving more space for nature	3.0-5.7 ton C/ha per year (Lamb et al. 2016[23])	RE	M	Land-based	Farm; region	Land	Strongly scale and context dependent if increasing impacts of intensive agriculture outweighs benefits of preventing deforestation	
Conversion of arable land to grassland		0.4-0.9 ton C/ha per year (Lugato et al. 2014); 0.23-0.75 ton C/ha per year (Soussana et al. 2004)	RE	M	Land-based	Farm	Land	Trade offs with land available for crop (food) production	Increases water retention; can be combined with enhancing species diversity and livestock feed strategies; reduces tillage; can be combined with increasing water tables i.e. wetland / peatland management

[23] Lamb, A., et al. (2016). "The potential for land sparing to offset greenhouse gas emissions from agriculture." Nature Climate Change 6(5): 488-492002E

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Abandoning organic soils / histosoils			RE	M	Land-based	Farm; region	Land	Trade-off with land available for crop (food) production,	
Wetland/peatland conservation /restoration			R, E	M	Land-based	Farm; region	Land		Increases water retention
Nitrification inhibitors	Block loss of nitrogen through volatilization and leaching of NH_4, NO_3^- and N_2O. With that, decrease GHG emission and increase N use efficiency	−4.5 (reduction) to +0.5 (increase) kg N2O-N ha^{-1} (Lam et al. 2017[24])	R	M	Land-based	Farm	Structure	Effects on GHG emissions, yields, and N uptake are contested and context dependent (Yang et al., 2016[25])	
Soil and nutrient management plans			RE	MA	Generic	Farm	Structure		Enhances uptake of all manure related and N fixation measures

[24] Lam, S. K., et al. (2017). "Using nitrification inhibitors to mitigate agricultural N2 O emission: a double-edged sword?" Glob Chang Biol 23(2): 485-489.

[25] Yang et al. 2016: Efficiency of two nitrification inhibitors (dicyandiamide and 3, 4-dimethypyrazole phosphate) on soil nitrogen transformations and plant productivity: a meta-analysis. Scientific Reports volume 6, Article number: 22075. doi:10.1038/srep22075

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Improved nitrogen efficiency			R	M	Crop production (including grass; including integrated with livestock); permanent crops. Any system that applies manure.	Farm	Structure		
Biological N fixation	N fixation through N fixating cover crops	-0.20 (emission) to 0.74 (sequestration) ton CO_2 e / ha per year[26], [27]	R	M	Land-based	Farm	Land		N fixating crops also provide general cover / catch crop functions.
Precision farming (Optimization of Nitrogen application rates)			R	M	Land-based	Farm	Both	High data and IT requirements	

[26] Kaye, J. P. and M. Quemada (2017). "Using cover crops to mitigate and adapt to climate change. A review." Agronomy for Sustainable Development 37(1).

[27] Sainju, U. M. (2016). "A Global Meta-Analysis on the Impact of Management Practices on Net Global Warming Potential and Greenhouse Gas Intensity from Cropland Soils." PLoS ONE 11(2): e0148527.

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Feed additives & feed management		3.5-7.6%	R	M	Livestock (dairy)	Farm	Structure	Affects land use for concentrate production	
Optimal manure management	Optimization of manure storage and transport to minimize emissions, or optimization of timing of manure application.	1.8-4.9%	RF	M	Livestock; *particularly land-based*	Farm	Structure		
Anaerobic digestors		1.8-4.9%	RF	M	Livestock	Farm	Structure	Landscape effects; need for manure transport; conflicts other manure uses	Offsets fossil fuel use
Breeding for feed efficiency		2.9%	R	M	Livestock (dairy)	Farm	Structure		
Disease management (livestock)			R	A	Livestock	Farm; region	Structure		
Disease management (pests)			R	A	Crop production	Farm; region	Land		Synergies with yield stability translate into some land sparing possibilities.

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Improved on-farm energy efficiency		2.7%	R	M	Generic	Farm	Structure	Biofuel: use of land Costs	With irrigation equipment
Carbon auditing tools			REF	MA	Generic	Farm	Structure	Can be labor intensive (see section 1.4)	Synergies with all other measures; can enhance uptake
Top-up for climate risks (floods, droughts, etc)		-		A	Generic	Farm	Structure		
Natural Water Retention Measures (reduced tillage)		n/a	R	A	Crop production	Farm	Both		Synergies with SOC sequestration through reduced tillage

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Crop diversification			RE	A	Crop production	Farm	Both	Can decrease yield	Can be combined with other crop related strategies (breeding); can increase yield, can reduce fertilizer needs, can increase SOC sequestration and water retention
Reducing stock densities in areas with natural handicaps / climate risks					Livestock, land-based	Farm	Structure		
Buffer strips	Primarily aims at reducing runoff and leaching.	0-0.37 ton C/ha per year (Smith et al. 2005; Martineau et al. 2016)	E	A	Crop production; permanent crops	Farm	Land		Increases carbon sequestration;
Enhance species diversity			RE	A(M)	Generic	Farm	Structure		

Measure	Notes	Quantification effect (reduction potential relative to total agricultural GHG emission unless noted otherwise)	Reducing emissions / enhancing sinks / fossil fuel offset (R/E/F)	Mitigation / Adaptation (M/A)	Farming system	Scale	Land / structure related	Trade-offs / limitations	Synergies
Irrigation practices, traditional terracing	Converting to more efficient irrigation practices with lower water losses; reducing runoff		-	A	Crop production , irrigated	Farm; region	Both		
Animal rearing conditions			-	A	Livestock	Farm	Structure		Can have synergies with general animal welfare issues
Risk management			-	A	Livestock	Farm	Structure		
Crop variety or cultivar selection			M: RE	M	Rice; Grassland; cropland	Farm	Structure	Can increase emission of other GHGs	
Grassland management ; meadow and pasture management		18% (Scherer and Verburg, 2018)	E	M	Livestock	Farm	Both		

1.3.4 Evaluation and messages for monitoring

Many climate smart agriculture measures apply in particular to a specific farming system, with particularly livestock having scope for a wide range of climate smart practices. About half of the CSA measures apply to all land-based systems. This segregation calls for indicators (and eventually labels) that are able to deal with the specifics of different farming systems and sets requirements for comparability and scope of comparison of different farms.

Measures are more or less equally divided between affecting farm structure and affecting land use and land cover, meaning that a combination of farm level statistics and spatial data is needed to measure CSA uptake and effects.

1.4 Data evaluation

A data description and evaluation table are in Annex 1: Evaluation of Farm Carbon Calculator tool inputs.

The European Farm Structure Survey (FSS) provides a solid and rather comprehensive set of data at European extent, however with a limited spatial resolution. A good data coverage is available at NUTS2 level while some statistics are provided at NUTS3 level and some statistics are only available on a per-country basis. Note that in many of the datasets provided largely at NUTS2 level through the FSS, Germany adopts another NUTS level. NUTS2 / NUTS3 data can be linked to vector data of the NUTS regions, enabling combination with other spatial data to calculate complete NUTSX level GHG accounts. Inconsistencies between countries with regard to priority NUTS levels for reporting make this difficult, as do changes in NUTS areas through the past decades.

Datasets through the FSS include both activity data on land use and some specifics on energy use that can be used for calculating climate change mitigation, as well as data on the uptake of adaptation measures. These include, for example, datasets on the uptake of different irrigation practices and total irrigation water use figures.

The FSS is normally based on a sample which is repeated every 2-3 years. Every 10 years, a census is conducted. In 2010, the census was supplemented with a Survey on Agricultural Production Measures (SAPM). This survey inventoried the uptake of a large range of CSA measures, both related to mitigation and adaptation. This includes, for example, tillage practices, and more detail on irrigation practices. Although content wise useful, the lack of a time series restricts the use of SAPM data for CSA monitoring.

The FADN data repository provides partly similar data as the FSS, e.g. on farm specific land use and crop areas as well as production figures and livestock numbers in categories. FADN provides more detail on energy use and on farm economics. With that, it provides a broader basis of activity data than FSS, although some of the datasets in FADN provide only indirect indicators based on costs rather than on e.g. fertilizer quantities.

The ESA Sentinel missions are promising for providing high-resolution, frequently updated, independent, activity data, inputs for direct carbon balance calculations, and some climate change adaptation proxies. Coupling to parcel information can add detail to registered parcel information on e.g. soil water content and productivity. The high resolution also enables capturing small woody features[28]. However, derivation of some of the proxies is

[28] https://land.copernicus.eu/pan-european/high-resolution-layers

still in the experimental stage. The frequent revisit time enables deriving information on land management including crop rotations[29] or grassland management intensity[30].

IACS-LPIS data is identified as the only dataset that makes a link between a farm and the location of the farm parcels. Thematic detail is limited with distinguishing only a few main land use types as well as landscape elements. On the other hand, IACS-LPIS puts strong emphasis on spatial accuracy of data. Spatial coupling of LPIS with any other spatially explicit data can be used to add thematic detail to farm level data. Databases are stored at member states, and given that the data is privacy sensitive, access is limited. As accurate modelling of carbon emission requires at least distinction of the main crop groups, IACS data cannot serve as an input.

The Netherlands has a wide range of land use and livestock management related activity data available at high spatial resolution. This includes detailed, and frequently updated, data on crop types and grassland of agricultural parcels. The Dutch parcel registration database is publicly available. The parcel database distinguishes 255 crop types including cover crops and catch crops, as well as 17 different landscape elements and ley farming. This dataset enables tracking land based CSA measures. A drawback is that the publicly available parcel data are not linked to farms. This lack of linkages to farm level data hampers application in farm level accounting. Both at European and Dutch scale, spatial coupling with LPIS data (data from the "gecombineerde opgave" (combined agricultural registration) might enable making the link.

The Dutch contribution to the EU level FSS (landbouwtelling) is an agricultural census performed annually across farms larger than EUR 3 000 standard output. Since 2018, it is combined with the official activity reporting for CAP and other subsidy purposes. It integrates compulsory parcel registration including land use at crop level and the reporting of landscape elements. Parcel delineation and crop / vegetation is openly available; access to the farm linkages is restricted.

FADN provides a relatively complete list of data that can be used to quantify uptake and effects of many CSA measures, at farm level. Because focusing on farm level accountancy, it does not contain accurate spatially explicit information on parcel location.

Additional to the data listed in the supplementary table, the Dutch "gecombineerde opgave" (combined agricultural registration) is worth mentioning. This system combines an agricultural census as well as IACS as a cross check with the acquisition of data required for subsidy allocation. Farmers are obliged to annually report on standard agricultural census issues and additionally on e.g. types of stables, rough grazing, weather insurance, agri environmental measures, detailed spatially explicit parcel information, and information on manure treatment. Part of the data is distributed in aggregated format as the Dutch contribution of the FSS and FADN; information on raw data availability and data quality is not available unless indication of a very high (>95%) completeness.

[29] https://www.researchgate.net/publication/326914613_Crop-Rotation_Structured_Classification_using_Multi-Source_Sentinel_Images_and_LPIS_for_Crop_Type_Mapping

[30] Estel, S., et al. (2018). "Combining satellite data and agricultural statistics to map grassland management intensity in Europe." Environmental Research Letters 13(7): 074020.

1.5 Recommendations

Activity data that can be related to CSA measures is widely available. Particularly land use / land cover data is available from specific data sources, but also data on energy use are available. Given that such different data sources are not completely consistent in defining different types of land use and land cover, combining land use and land cover data from different sources might lead to accuracy and consistency issues.

Data on the results of implementation of climate smart agriculture measures are scarcer and, if available, are of lower quality. While results of water reduction measures could be derived from data on irrigation, results of CSA measures related to reduction of GHG emission or sequestration of soil organic carbon can only be derived from model based estimations. GHG emissions at farm level are not measured by default and while soil organic carbon stocks are regularly measured across the EU through the LUCAS sampling since 2009, the sampling strategy does not allow estimating SOC stock changes in a sufficiently accurate manner. SOC changes over the timeframe considered are likely smaller than the total measurement error. Lack of actual data on livestock emissions also gives rise to uncertainty.

At aggregated level (NUTS2; potentially NUTS3) sufficient data is available to calculate a comprehensive GHG account at multiple timesteps, allowing for tracking effects of management and land cover changes on GHG emissions. Data from farm statistics and spatially explicit data can be aggregated to a common resolution.

At farm level, data from FSS and FADN might be most applicable and contain activity data with a sufficient level of thematic detail. Data could be made available on request. A challenge for calculating farm level GHG accounts top-down is the spatially explicit data on farm and parcel locations. Some carbon calculation tools require basic information on soil types. While this information is normally available to the farmer for his/her parcels, information on the location of parcels belonging to each farm is normally not openly available, hampering consideration of main soil characteristics in calculating carbon balances. Some carbon calculation tools do not require soil information and can calculate farm level carbon balances based on just statistical information on crop areas. FADN and FSS both have a revisit time of 2-3 years, which renders a risk of information being outdated. Remote sensing data acquired through the Sentinel programme could supplement this with high-resolution, frequently updated information on land cover. If combined with IACS data, this allows for a higher monitoring frequency, as implemented in EU regulation 2018/746[31].

At the scale of the Netherlands, a census consistent with FSS is done annually. The census also includes spatially explicit registration of farm parcels and its land use, consistent with IACS-LPIS. The census is linked to CAP reporting and is compulsory, resulting in a near-to 100% response rate. Coupling such a census to a carbon calculation tool can provide relatively frequently updated, farm level carbon accounts.

[31] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1526990310967&uri=CELEX:32018R0746

2. Task 2a: evaluation of existing tools

2.1 Introduction

Task 1 of this study created an overview of databases, indicators, and farm carbon tools that might be of relevance for quantifying and monitoring uptake and effect of climate smart agriculture measures in the EU. Based on these overviews, as first step of Task 2: Identification of the climate action potential of existing farms in the GIS, the use in practice of different farm carbon tools has been explored in practice, and relevant data for calculating farm carbon balances was collected and harmonized. Although this study (as a consequence of the available data) concentrates on mitigation measures, a brief exploration of quantifying adaptation practices was also done.

Using the identified potentially suitable tools, draft indicators for CSA uptake and effectiveness were calculated at farm and EU level. With a subset of tools, an exploration of mitigation / adaptation potential was performed at EU level.

Task 1 also inventoried which CSA measures exist and explored which data could potentially be used for quantification and monitoring of these specific measures. Following the overview, Task 2 quantifies for a selected set of measures the current uptake as well as a broad indication of the overall potential for uptake.

Upon monitoring CSA, the availability of timely information on the of measures is essential. Farmers should be able to provide data on measure uptake, meaning that clear and relevant indicators should be available for which data requirements are feasible. At the same time, indicators should be accessible to government bodies that monitor progress. For reporting, internet access is essential. Therefore, we explored to what extent farmers would be able to quickly report changes, i.e. would be able to keep a monitoring system and a label up-to-date. Timeliness of currently and shortly available data was discussed.

2.2 Methods

2.2.1 Overview

Task 1 identified a wide range of activity data potentially suitable for calculating farm carbon accounts. This includes European-scale survey and inventory data at farm level or NUTS2 level, as well as spatial data at different resolutions and data that could serve for a detailed case study in the Netherlands. Task 1 also identified three farm carbon tools that were deemed suitable to calculate farm carbon accounts. This includes the **EX-ACT** tool[32] for large-scale (NUTS2) analysis, and the **Farm Carbon Calculator (FCC)**[33] and the Carbon Calculator to promote Low-Carbon Farming practices (**LC-Farm**)[34] tools for a farm level analysis. Additionally, the **SOSTARE** tool was evaluated. SOSTARE was initially disregarded because of the too large simplicity and the lack of coverage of all farm types, but because of data constraints encountered upon evaluation of the aforementioned tool, it was included in the evaluation at farm and European scale.

In the first part of this task, activity data and emission factors were collected and harmonized, using the selected tools as a guidance. Each tool was filled in systematically

[32] Food and agriculture organisation 2018: News, Available at: http://www.fao.org/tc/exact/ex-act-home/en/. Accessed 04.12.2018.

[33] Carbon Calculator, 2018. Available at: https://www.cffcarboncalculator.org.uk. Accessed 20.11.2018.

[34] JRC for DG ENV

for a specific (set of) sample region(s) or (set of) sample farm(s). Data required by the tool for each calculation step was extracted from a previously identified data base, converted in the right format, and entered in the tool. Generally, tools require farm or region-specific activity data and calculate greenhouse gas balances using either predefined or user defined emission factors. For some of the required activity data, multiple data sources were available. In these cases, the “best available” data were used, i.e. either based on data quality reported in metadata or (scientific) evaluations, or the most recent, highest resolution data with the best thematic resolution. Data extraction was done for the whole European territory / the full set of farm data available. The testing of the tool thus resulted in a complete dataset for calculating farm or region carbon accounts.

During data collection, data sources and data gaps were registered in a table. This resulted in an overview of the data gaps for each specific tool.

2.2.2 Case studies for tool evaluations

The evaluation was done using a small set of farms in the centre of the Netherlands (Figure 1 and Figure 2; Table 2; Table 3) for the farm level tools, for a single NUTS2 region for the EX-ACT tool (Figure 4), and at European scale for the SOSTARE tool. Farm location and field data locations as well as manure balances, activity data regarding livestock, and total production, import, and export of feed, forage, and manure are officially registered at farm level. A national level database of these farm level data appeared not accessible; farmers have to register and store these data individually and a varying sample of farms is officially checked annually[35]. For the 25 farms, FADN data and location data are available. These were combined with national- and European level spatial data. The total set of input data is added as an excel file annex[36].

[35] rijksdienst voor ondernemend nederland, 2018: Mestbeleid. Availalbe at: https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid. Accessed 13.10.2018

[36] Sheet Appendix_farmdata

Table 2: Land use and cover at sample farms (full data in excel annex[5])

ID	TF14	AWU (persons)	UAA (ha)	Field crops (ha)	Orchards (ha)	Permanent grasslands (ha)	SLE and woodland (m2)	Wetlands (m2)	Green manure crops (ha)	Field crops (ha)
1	Specialist milk	1.1	34.5	0.0	0.0	34.5	328.1	0.0	0.0	0.0
2	Specialist milk	1.0	28.7	0.0	0.1	28.7	7.8	0.0	0.0	0.0
3	Specialist fruit orchards	7.1	26.4	0.0	19.3	0.0	0.0	0.0	0.0	0.0
4	Specialist milk	1.9	27.7	0.0	0.0	27.7	0.0	0.0	0.0	0.0
5	Specialist milk	2.0	28.7	0.0	0.2	28.7	0.0	140.0	3.9	0.0
6	Specialist milk	1.9	66.0	0.0	0.2	66.0	39.1	0.0	6.0	0.0
7	Specialist milk	3.1	135.3	27.8	0.5	107.5	15.6	0.0	0.0	27.8
8	Specialist milk	1.0	20.0	0.0	0.1	20.0	93.8	0.0	0.5	0.0
9	Specialist milk	2.1	31.3	9.4	0.2	20.9	156.3	0.0	0.2	9.4
10	Specialist granivores	0.5	1.7	1.6	0.0	0.2	70.3	0.0	0.0	1.6
11	Specialist cattle	0.7	23.2	0.0	0.1	23.2	101.6	0.0	0.0	0.0
12	Specialist milk	1.0	8.5	0.0	0.2	8.5	23.4	0.0	0.0	0.0
13	Specialist granivores	2.3	7.1	0.0	0.0	7.1	23.4	0.0	0.9	0.0
14	Mixed livestock	1.1	18.6	0.0	0.5	18.6	46.9	0.0	1.1	0.0
15	Specialist milk	2.3	84.6	20.3	0.2	64.4	375.0	0.0	0.0	20.3
16	Specialist sheep and goats	0.5	13.8	0.0	0.0	13.8	31.3	0.0	0.0	0.0
17	Specialist granivores	1.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
18	Specialist milk	1.0	28.8	6.5	0.1	22.3	93.8	0.0	0.0	6.5
19	Specialist milk	1.1	20.3	4.1	0.0	16.2	0.0	0.0	0.00	4.1
20	Specialist granivores	4.4	2.9	0.0	0.0	2.9	7.8	0.0	0.00	0.0

ID	TF14	AWU (persons)	UAA (ha)	Field crops (ha)	Orchards (ha)	Permanent grasslands (ha)	SLE and woodland (m2)	Wetlands (m2)	Green manure crops (ha)	Field crops (ha)
21	Specialist milk	3.2	65.9	0.0	0.5	65.9	39.1	0.0	0.00	0.0
22	Specialist horticulture	1.8	6.8	0.3	0.0	6.3	23.4	0.0	0.00	0.3
23	Specialist fruit orchards	2.5	5.6	0.0	4.2	0.0	0.0	0.0	0.00	0.0
24	Specialist fruit orchards	4.5	17.6	0.0	10.8	0.0	0.0	0.0	0.00	0.0
25	Specialist fruit orchards	0.5	3.0	0.0	3.0	0.0	0.0	0.0	0.00	0.0

Table 3: Livestock at sample farms (full data in excel annex)

ID	TF14	AWU (persons)	UAA (ha)	Livestock units (LSU)	Dairy cows (heads)	Other cattle (heads)	Sheep and goats (heads)	Pigs (heads)	Poultry (heads)	Kilo milk per head
1	Specialist milk	1.1	34.5	22.0	8.2	13.0	0.9	0.0	0.0	1341.5
2	Specialist milk	1.0	28.7	72.6	52.9	19.7	0.0	0.0	0.0	7761.8
3	Specialist fruit orchards	7.1	26.4	156.0	0.0	156.0	0.0	0.0	0.0	0
4	Specialist milk	1.9	27.7	75.5	65.1	5.5	5.0	0.0	0.0	7929.3
5	Specialist milk	2.0	28.7	84.9	59.5	24.2	1.2	0.0	0.0	7431.9
6	Specialist milk	1.9	66.0	146.1	96.8	39.9	9.4	0.0	0.0	8351.2
7	Specialist milk	3.1	135.3	498.8	304.2	136.6	0.0	58.1	0.0	7266.3
8	Specialist milk	1.0	20.0	45.6	34.2	11.4	0.0	0.0	0.0	6649.1
9	Specialist milk	2.1	31.3	49.7	29.1	20.6	0.0	0.0	0.0	8443.3
10	Specialist granivores	0.5	1.7	249.6	0.0	0.0	0.0	249.6	0.0	0
11	Specialist cattle	0.7	23.2	46.4	0.0	46.4	0.0	0.0	0.0	0.0
12	Specialist milk	1.0	8.5	31.9	21.3	10.6	0.0	0.0	0.0	8399.1
13	Specialist granivores	2.3	7.1	316.3	0.0	0.0	0.0	73.2	243.1	0.0
14	Mixed livestock	1.1	18.6	49.6	23.2	8.2	0.0	11.8	0.0	9241.4
15	Specialist milk	2.3	84.6	199.5	164.2	35.3	0.0	0.0	0.0	9254.0
16	Specialist sheep and goats	0.5	13.8	13.5	0.0	0.0	13.5	0.0	0.0	0.0
17	Specialist granivores	1.5	0.0	612.7	0.0	0.0	0.0	612.7	0.0	0.0
18	Specialist milk	1.0	28.8	66.2	50.1	16.1	0.0	0.0	0.0	7598.8
19	Specialist milk	1.1	20.3	50.6	34.0	16.6	0.0	0.0	0.0	7282.3
20	Specialist granivores	4.4	2.9	1342.7	0.0	6.4	0.0	1299.8	36.5	0.0
21	Specialist milk	3.2	65.9	420.8	295.0	122.1	3.7	0.0	0.0	8397.3

ID	TF14	AWU (persons)	UAA (ha)	Livestock units (LSU)	Dairy cows (heads)	Other cattle (heads)	Sheep and goats (heads)	Pigs (heads)	Poultry (heads)	Kilo milk per head
22	Specialist horticulture	1.8	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	Specialist fruit orchards	2.5	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	Specialist fruit orchards	4.5	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	Specialist fruit orchards	0.5	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 2. Location of study areas in the Netherlands

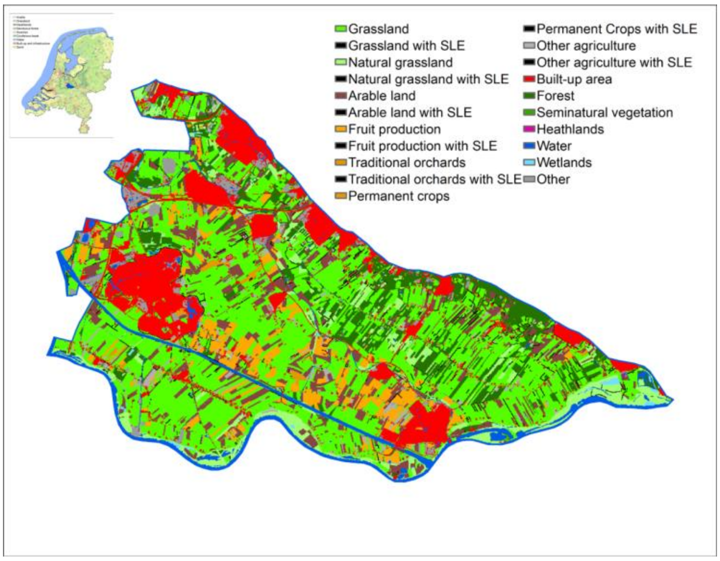
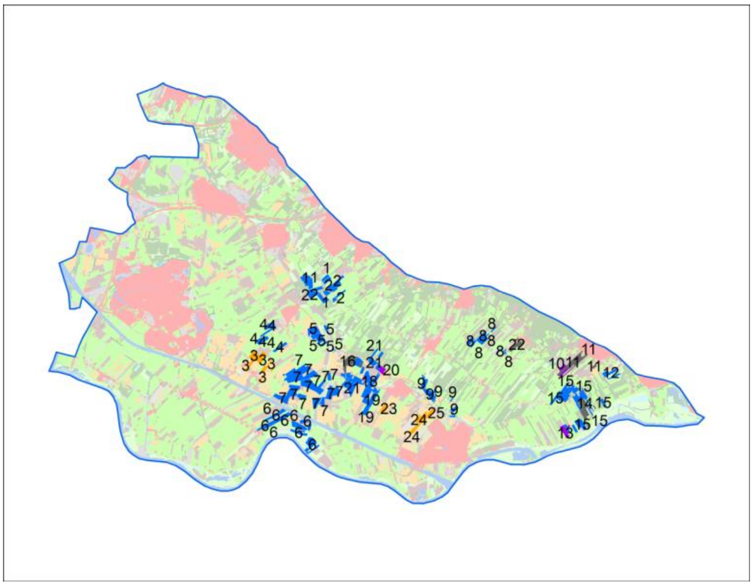


Figure 3. Location of sample farms in the study area



Blue parcels indicate dairy farms, orange parcels indicate fruit farms, purple parcels indicate granivore farms, grey parcels indicate other farms (Background map from Verhagen et al. (2018)[37]

[37] Verhagen et al. 2018: Optimizing the allocation of agri-environment measures to navigate the trade-offs between ecosystem services, biodiversity and agricultural production." Environmental Science & Policy **84**: 186-196

Figure 4. Corine Land Cover 2000 (left) and 2012 (right) in the Friesland Province (NUTS2 region NL12)

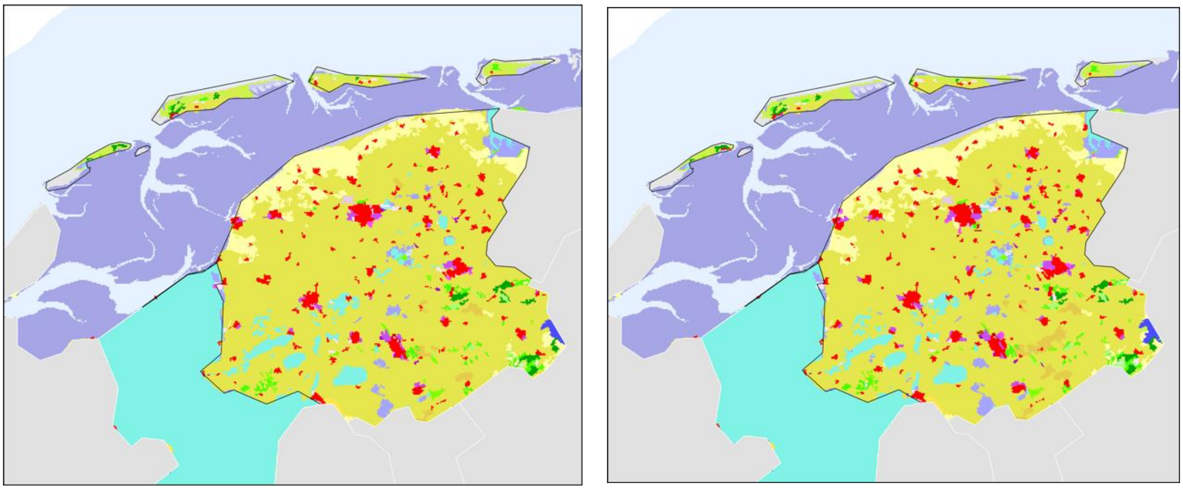


Table 4 Land use change matrix 2000 – 2012 of Friesland province

ha 2000v, ha 2012 >	Degraded	Annuals	Flooded rice	Perennial / tree crop	Grassland	Forest	Other
Degraded	19756	56	0	31	488	13	106
Annuals	419	28506	0	0	269	31	244
Flooded rice	0	0	0	0	0	0	0
Perennial / tree crop	6	0	0	3150	19	0	0
Grassland	3650	2206	0	2331	246538	556	2463
Forest	213	6	0	31	356	7431	194
Other	106	31	0	0	606	31	33144

2.2.3 Carbon tools

2.2.2.1. Tool selection approach

As a boundary condition, we explored the potential of farm carbon tools for a more general application using regular inventory data as inputs. An internet search for carbon calculation tools yielded 815 hits, which included four recent evaluations of carbon tools and some additional tools, and furthermore overlapped to a very large extent. Additional tools were identified by the EC.

Evaluations of carbon tools included firstly Denef et al. (2012)[38] who reviewed carbon calculators in 2012. Secondly, Peter et al. (2017)[39] reviewed carbon calculation tools

[38] Denef et al. 2012: Report of Greenhouse Gas Accounting Tools for Agriculture and Forestry Sectors, Interim report to USDA under Contract No. GS-23F-8182H.

[39] Peter et al. 2017: Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – A review of carbon footprint calculators, Renewable and Sustainable Energy Reviews 67: 461-476. https://doi.org/10.1016/j.rser.2016.09.059.

targeted at energy crop production. The review by Peter et al. inventories 44 tools, that all focused on the carbon balance of bioenergy production. Whittaker et al. (2013)[40] did a multi criteria analysis of 6 farm based tools and 5 biofuel tools. A fourth review is Colomb et al. (2012)[41].

Despite relatively recent publication, several of the tools are not accessible anymore, or not openly available at all (e.g. Australian FarmGas tool). Moreover, there is strong overlap among the reviews.

Four tools were selected for a deeper evaluation. Another six tools were identified, but disregarded because of apparent input data demands. This section first describes the tools that were scrutinized and briefly evaluates the other tools.

2.2.2.2. Tools included in further analysis

LC Farm Carbon Calculator

The LC Farm Carbon Calculator (LC-Farm) is a farm level tool that contains a set of emission factors that, through a calculation tool, can be coupled to activity data. The tool calculates GHG emission of a farm, compares it to other, similar, farms, identifies top-5 sources, and allocates emissions over different gases. The tool enables coupling activity data to products that leave the farm gate, enabling application for calculating GHG emissions per unit product within a cradle-to-farm boundary. Secondly, the LC Farm Carbon Calculator can help identifying possible GHG reduction actions and quantify potential GHG savings.

The tool requires data on livestock herd size, distribution, and manure management, crop type and yield and residue management, energy use, buildings and materials, and secondary inputs and organic matter flows and cooling. The tool distinguishes different greenhouse gases. The tool is life cycle based and calculates farm level emissions and sequestration using an Excel and VBA based calculation. It is suitable for the most common types of farming in the EU.

Data sources for emission factors mainly include IPCC Tier 2, supplemented with data originating from EU, international, and MS level inventories (Tuomisto et al. 2015).

LC-Farm was applied on a set of farms in the Utrecht province, Netherlands, to test the tool. Farm perimeters are available that can be coupled to high-resolution spatial data on land cover and land use. Farm statistics are available as well; these include the data reported to FADN.

Farm Carbon Cutting Toolkit / Farm Carbon Calculator

The Farm Carbon Calculator (FCC) is an UK based tool that calculates a farm level carbon footprint from cradle to gate. Although the tool is primarily targeted at organic farmers, it is widely applicable. The tool calculates annual carbon emission, sequestration and balance. This is translated into per-hectare figures, as well as translated into product specific quantities. Next, the tool identifies most important sources of GHGs. Carbon sequestration is included in woodlands, permanent field margins, hedges, and soil.

[40] Whittaker et al. 2013: A comparison of carbon accounting tools for arable crops in the United Kingdom, Environmental Modelling & Software 46: 228-239. https://doi.org/10.1016/j.envsoft.2013.03.015.

[41] Colomb et al. 2012: REVIEW OF GHG CALCULATORS IN AGRICULTURE AND FORESTRY SECTORS. A Guideline for Appropriate Choice and Use of Landscape Based Tools, ADEME, IRD, FAO

Input data include fuel use, building construction materials, farm machinery and other capital items, crop yields, fertilizer use including the consideration of green manure, peat soil cultivation, agro-chemical use, livestock size, composition and feed, manure handling, waste production and handling, distribution of products, and sequestration in orchards, vineyards, woodlands, hedges, field margins, permanent wetlands, as well as soil organic matter changes.

For calculating GHG emissions and sequestration, a collection of scientific and popular references and databases are used, which are often specific to the UK. Emission factors originate from a large variety of sources. This enables accounting for a wide range of topics, but in some cases might compromise consistency. Applying UK-specific data on case studies outside the UK might introduce further uncertainties. The FCC was tested on the same set of farms in the Dutch Utrecht province as the LC-Farm tool.

EX-ACT[42]

EX-ACT is a larger scale tool, that is developed to provide estimates of the impact of agriculture and forestry development projects, programmes and policies on the carbon balance. It is a land-based tool and estimates C stock changes and GHG emissions per unit of land. Project based GHG balances are compared against a Business as Usual or present-day situation. With that, the effect of CSA measures implementation can be quantified. The tool has a project, or e.g. the implementation of a set of actions, as calculation boundary, meaning that dependent on the application the boundary can be set at a farm or a spatial unit such as a NUTS region.

EX-ACT distinguishes broad crop categories, broad land use classes, broad livestock classes, and adopts a broad categorization of management actions. It does include peatland management and fire regimes and can deal with energy consumption and construction of new infrastructure.

EX-ACT largely builds on IPCC Tier 1 and Tier 2 emission factor data. Among the tools evaluated, EX-ACT is the least data intensive and the easiest to apply. This goes at the cost of the accuracy and the sensitivity to management changes.

The EX-ACT tool was tested using land use changes between 2009 and 2012 in the Dutch province of Friesland, a NUTS2 region in the north of the country facing a challenge of livestock climate impacts.

SOSTARE[43]

SOSTARE is a tool for calculating a broad sustainability indicator. It builds on 37 indicators that are aggregated into 12 themes: cropping system, fertilizers management, energy management, water management, agrochemicals management, value of production, value added, farm household income, CAP independence, farm business diversification, natural value, functional landscape pattern. Upon aggregating, dimensionless indices of the 12 themes are created that are displayed in a radar plot to allow qualitative analysis of trade-offs.

The tool allows comparison of different management schemes, which can be quantified using the 37 indicators and be jointly visualized. The tool is farm specific.

[42] Food and agriculture organisation 2018: News, Available at: http://www.fao.org/tc/exact/ex-act-home/en/. Accessed 04.12.2018

[43] JRC for region Lombardia

Finally, we did a data-driven calculation of greenhouse gas balances at farm scale. This included emissions from land use, livestock, and energy use. We collected and harmonized data for the calculation of a greenhouse gas account for land use change and livestock. Activity data on these two topics are of reasonable quality, and are not optimally used in the other tools. Together with overall emission factors, these activity data were utilized to obtain a spatially disaggregated greenhouse gas account.

2.2.2.3. Tools disregarded in further analysis

COMET-VR/2.0/FARM [44]

COMET is a web-based tool, linked to the CENTURY soil carbon model, for estimating changes in soil carbon storage and GHG emission from agricultural management in the conterminous United States. Data behind the calculations are either IPCC Tier 1 and Tier 2 emission factors, or are based on American statistical or inventory data. Strengths of the different versions of COMET include the web based application and the good representation of soil organic carbon changes through an established process model. The tool was disregarded because of the parameterization with American and Tier 1 data, and the high data requirements.

Cool Farm Tool[45]

The Cool Farm Tool quantifies a full on-farm greenhouse gas and soil carbon balance. The tool uses the farm boundaries as boundary conditions and works on a per-product basis. Emission factors used for calculations include a broad range of IPCC and other global datasets, which are both scientific meta-analysis based as well as industry derived datasets. The Cool Farm Tool is supported by the Cool Farm Alliance. This embedding in a business network might be an asset for labelling purposes. The data sources for emission factors might be not completely consistent, which is a weakness, and the data are to a large extent global-scale data that might be less applicable to European scale. The quantitative output is a strength of the tool, although the product-based focus is a limitation for the current study.

Dialecte[46]

Dialecte is a tool to assess the environmental performance of farms, applicable to any farming system in Europe. It assesses sustainability of agricultural production at large. The tool provides semi-quantitative outputs where all indicators are scored through a point system instead of quantifications of the GHG balance, which is a major limitation of the tool.

Austrian Carbon Calculator[47]

This tool quantifies the effect of different agricultural management practices on soil carbon sequestration. The tool can account for the effects of different crop rotations, management

[44] Comet Farm, 2018: Voluntary Reporting Carbon Management - Online Reporting Tool. Available at: http://cometfarm.nrel.colostate.edu/. Accessed 08/11/2018

[45] Cool Farming 2018. Available at: https://coolfarmtool.org/. Accessed 29.10.2018

[46] Pointereau et al. 2018: DIALECTE, a comprehensive and quick tool to assess the agro-environmental performance of farms.

[47] Umweltbundesamt, 2018: Kohlenstoff-Rechner für produktive Böden. Available at: http://www.umweltbundesamt.at/acc. Accessed on 23.10.2018

of crop residues, use of organic fertilizers, catch crops with or without aboveground biomass left on field, different tillage practices, and different irrigation practices. The tool was disregarded because it does not provide a full carbon balance.

Bord Bia Carbon navigator[48]

The Carbon Navigator is developed by the Irish institutes Teagasc and Bord Bia. The tool aims to improve the carbon efficiency of Irish agriculture, by providing a comparison with peer farms and targets with regard to a few key indicators, and incentivizing actions for moving to the target. The system focuses on beef and dairy farming.

The Carbon Navigator is a carbon accounting system that is directly linked to key national databases, i.e. the Animal Identification and Movement system and animal genetic and breeding information from the Irish Cattle Breeding Federation. The information system also has access to detailed data on land use. Farmers are obliged to use the carbon navigator to report their progress to targets. The tool was not included in further analyses because of the specific focus on livestock farms.

Kringloopwijzer[49]

A sustainability initiative by the Dutch dairy sector developed a nutrient management tool that initially aimed at quantifying phosphate and nitrate emissions. Farm level GHG emissions have been included as an add-on. Since 2017, dairy farmers are obliged to provide information through the *Kringloopwijzer.*

As with the Bord Bia carbon navigator, the focus on a specific sector limits the usability for the current project.

Capri

Although CAPRI is not a farm carbon tool but an EU scale economic modelling framework[50], it is briefly mentioned in this section. It is widely used for analysing effects of market policies and agricultural policies on land use and impacts of land use (e.g. Lotze-Campen et al. 2017[51]). Simulations can be done on NUTS2 level or for 2450 farm- region combinations and can include greenhouse gas emissions from 50 land or livestock based activities. The model does not include other farm emissions from e.g. energy, buildings, or machinery.

[48] Murphy et al. 2013: The Carbon Navigator: A decision support tool to reduce greenhouse gas emissions from livestock production systems, Animal, 7(S2), 427-436. doi:10.1017/S1751731113000906

[49] Schröder et al. 2014: Rekenregels van de KringloopWijzer, Achtergronden van BEX, BEA, BEN, BEP en BEC, Plant Research International, onderdeel van Wageningen UR, Business Unit Agrosysteemkunde. Report 553. http://edepot.wur.nl/296259

[50] www.capri-model.org

[51] Lotze-Campen, H., et al. (2017). "A cross-scale impact assessment of European nature protection policies under contrasting future socio-economic pathways." Regional Environmental Change **18**(3): 751-762.

2.3 Results: Farm specific tools

2.3.1 Farm Carbon Calculator

The Farm Carbon Calculator collects data on the categories carbon sequestration, distribution and refrigeration, waste, livestock, agrochemical use, fertility (production and manure and fertilizer use), capital items, materials, and fuels. Table 5 summarizes to what extent data required are available in existing databases. A full evaluation of the inputs is given in Annex 1: Evaluation of Farm Carbon Calculator tool inputs.

Table 5 broad overview of data requirements, data sources, and data availability for the FCC

Data category	Broad description of inputs required	Overview of data sources	Data availability (indicators with sufficient data / total indicators in category) (numbers)
Carbon sequestration	Area and broad vegetation description of land use that could sequester carbon	FADN, Dutch parcel registration, Dutch tree maps, Copernicus High Resolution data	16 / 16
Distribution	Distance over which farm products are distributed and means of transport	No data	0 / 12
Waste	Type, quantity, and way of disposal	No data	0 / 36
Livestock	Herd size and composition, manure quantity and handling, feed quantity and practices	FADN; Dutch farm level administration, large data gaps	46 / 109
Agrochemicals	Quantity and type of fertilizers and crop protection	Dutch farm level administration, large data gaps	3 / 23
Fertility	Yields, type and quantity of soil improvers	FADN; Dutch farm level administration, large data gaps	27 / 41
Capital items	Machinery, vehicles, road paving, water systems etc (long-term depreciation)	No data	0 / 43
Buildings, machinery, materials	Machinery, vehicles, road paving, water systems etc (short-term depreciation)	No data	0 / 41
Fuel	Consumption of electricity and fuel as well as transport distances	No data; only approximations through costs possible.	0 / 28

Openly available data as listed in Table 5 allowed calculating partial carbon balances at farm level, only including the categories of carbon sequestration, livestock, and fertility. Although sufficient data is available for approximating carbon sequestration, this category requires spatial as well as empirical data from multiple sources. Generally, spatial data fall short in the required level of thematic detail. Furthermore, establishing the linkage between different datasets of different resolution renders a risk of uncertainties. Required data for including soil organic carbon loss can be approximated from Dutch or European level spatial datasets, but with a large uncertainty. For calculating livestock emission data, as well as fertilizer application, the available data lacks the required thematical detail. Furthermore, data on feed are not available. Data on crop protection lack thematic detail and are restricted, while sampling consistency and revisit time also reduce the relevance of the data for monitoring purposes. Data on annual yields were extracted from the Atlas Natural Capital that includes a special field level spatial explicit dataset of percentages of NUTS2 level yield obtained, which is utilized to calculate the required farm level production figures. Data on compost and composted manure as well as mineral fertilizer are among obligatory data collection at national level. Data on lime use and plant raising material is not available. The area of cultivated peat soils can be derived from soil maps and parcel data; green manure coverage is to a large extent available from parcel land use statistics.

Table 6: emission and sequestration per farm as calculated using the Farm Carbon Calculator.

FARMID	emission (ton CO_2 eq per year)	sequestration (ton CO_2 / year)
1	24.8	0.314
2	189.9	0.388
3	212.2	7.340
4	7.8	0
5	35.2	0.675
6	60.0	0.697
7	252.7	1.665
8	113.5	0.330
9	121.0	1.469
10	68.7	0
11	61.9	0.428
12	14.8	0.682
13	111.2	0.022
14	95.1	1.695
15	641.6	0.660
16	6.5	0.030
17	15.6	0.330
18	175.9	0.420
19	126.8	0
20	354.1	0.008
21	1100.0	1.687
22	0.0	0.022
23	0.0	13.860
24	1.4	35.640
25	0.0	9.900

Farm specific partial carbon balances were calculated (Table 6) that included land and livestock based inputs. These demonstrate that for dairy farms with (permanent) pasture (Table 2, Table 3) carbon sequestration does not outweigh emission from livestock, while permanent crop farms sequester considerable amounts of carbon.

Altogether, carbon sequestration, land use and livestock issues are to a large extent quantifiable with the Farm Carbon Calculator (Table 6), although uncertainties in particularly the carbon sequestration calculation are large.

A broader inventory of greenhouse gas emissions is hampered by a lack of data. Nevertheless, as we were able to calculate a reasonably complete account of carbon sequestration and all the missing data regard emission, altogether, emissions of farms are underestimated in the current analysis. A limitation of the tool for general usage is the focus on the UK, with UK specific emission factors. A second limitation is an imbalance between data needs and level of detail in calculations. For example, a high level of detail about fertilizers used is required, but no detail on density of use is required, nor insight in water tables in fields that are fertilized, while this has a large impact on greenhouse gas emissions compared to the raw quantity of fertilizers.

2.3.2 LC-Farm

LC-Farm assesses greenhouse gas balances for ten different categories. Table 7 summarizes the data availability of LC-Farm. A full evaluation of the input data availability can be found in Annex 2: Evaluation of LC Farm inputs.

Strengths of the tool include the applicability to the EU and to a variety of farming systems. Data use is transparent, independent, and consistent. Data requirements are high, but this enables giving a complete picture of farm level GHG balances. To a large part, the tool would also be applicable on groups of farmers. Weaknesses are the emission factor-based approach for calculating SOC emissions, which, over the short time frames considered, tend to be uncertain. The quantitative output is an asset. With the applicability to a wide range of farming systems and the inclusion of many GHG sources, it can account for effects of an array of CSA measures.

Altogether, use of the LC-Farm tool based on existing, top-down data is subject to considerable data gaps. The tool requires a high level of detail on food and feed practices that is not available. Manure data required shows a reasonable match with the mandatory manure administration of the Netherlands, but even under these data-rich conditions the thematic gaps were so large that calculations could not be performed. Many details on livestock herd composition, that would benefit accuracy of calculation, are not available. Although the basic data on crop production required by the tool are available in multiple databases, some essential data are currently of poor quality. The LC-Farm tool utilizes data on irrigation and soil conservation practices that do not match data availability and the same applies to residue management. Data on energy, buildings, materials, cooling are not available. The inclusion of natural elements and land use change lacks flexibility. Although data are partly available, the specific format required by the tool limits the actual use of existing data. The tool checks for consistency across categories (e.g. if pigs are entered, also food has to be entered). When using the tool for a single farm with complete data, this strongly enhances the robustness of the tool. Upon filling LC-Farm with top-down data, the cross-check makes calculation of a partial GHG balances impossible. As a consequence, farm level accounts could not be calculated.

Table 7 Broad overview of data requirements, data sources, and data availability for LC-Farm

Data category	Broad description of inputs required	Overview of data sources	Data availability (indicators with sufficient data / total indicators in category) (numbers)
General	Farm size, organic Y/N, nitrate vulnerable zones Y/N	FADN, EU level spatial data	5 / 5
Pedoclimatic conditions	Information on dominant soil characteristics and seasonal level climate characteristics	EU and global scale spatial data	9 / 9
Livestock	Herd size and composition, production quantity and composition, feeding practices and quantities	FADN, FSS, Dutch farm level administration. Large data gaps.	28 / 139
Crop production	Areas, yields, management practices incl tillage, manure, fertilization, irrigation, cover crops	FADN, FSS, Dutch parcel registration, Dutch farm level administration. Large data gaps.	17 / 59
Energy	Consumption and type of fuel,	FADN; large data gaps	1 / 22
Water	Consumption and utilization of water	No data	0 / 3
Natural elements	Area and boundary length of hedges, shrubs, and other natural elements	Dutch parcel registration	10 / 14
Buildings and materials	Size, type, and material used for farm built area	No data	0 / 37
Machinery	Tractors and machinery; number, size, use frequency	No data	0 / 26
Cooling	Quantity, capacity and frequency of use of cooling equipment	No data	0 / 23
Organic matter flows	Exchange of organic matter with other farms	Dutch manure registration; large data gaps	1 / 5

2.3.3 SOSTARE and data-driven calculation of farm carbon balances

SOSTARE uses data on crop rotations, legumes, grassland area, tilled area, organic matter, NPK balance at farm gate, fossil energy use, energy efficiency, linear elements. The possibility to navigate trade-offs and communicate them in a clear and easily understandable way is an asset of the tool. Also, the wide range of topics included is an asset. Although not all factors are related to CSA, the factors that are relevant provide a broad coverage of CSA topics and measures.

The tool calculates indices for 7 topics, which can either be presented separately or be aggregated. After an initial exploration of farm carbon tools, SOSTARE was disregarded because (1) it did not provide the possibility to explicitly include greenhouse gas emissions from livestock, and (2) SOSTARE provides an overall, semi-quantitative, index of sustainability, which was deemed inferior to the emission quantities estimated by the other tools. Given the data constraints encountered during the development of databases that could be utilized to feed the other two tools, SOSTARE was reconsidered. The tool was evaluated in the same way as EX-ACT, LC-Farm and FCC, by systematically quantifying the tool output while collecting data, at both farm scale and European scale with a NUTS2 resolution.

Table 8 provides an inventory of the data needs of the SOSTARE tool. A full evaluation of the inputs of the original SOSTARE tool is in Table 8.

Table 8 broad overview of data requirements, data sources, and data availability for SOSTARE

Data category	Broad description of inputs required	Overview of data sources	Data availability (indicators with sufficient data / total indicators in category) (numbers)
Cropping system and soil fertility	Level of implementation of different practices, such as multicropping, double cropping, legumes, winter cover, ploughing	FADN; LUCAS	7 / 7
Nutrient application and management	Farm-scale balances for N, P, K	No data	2 / 4
Consumption of non-renewable energy	Direct and indirect energy consumption, energy output	Could be approximated using FADN, FSS, and auxiliary data sources, but there are large data gaps	1 / 4
Water resource management	Irrigated area; extent of irrigation practices	FADN, LUCAS	1 / 3
Agrochemical management	Disregarded because of limited relevance for CSA	No data	0 / 5
Economic indicators	Disregarded because of limited relevance for CSA	FADN	9 / 9
Ecological indicators	Coverage of linear elements and natural vegetation patches, woodland areas, and habitat structure indicators	FADN; Dutch parcel data	3 / 3

SOSTARE was developed with the aim of quantifying a broad sustainability indicator. Therefore, the tool does not require quantification of greenhouse gas emissions from livestock. This is a considerable shortcoming upon quantification of CSA potential or uptake Using livestock numbers from FSS (European scale) and FADN (farm scale) and emission factors from the IPCC emission factor database[52], farm or regional specific livestock emissions can be easily approximated.

[52] International Panel for Climate Change, 2018: Emission factor database. Available at: https://www.ipcc-nggip.iges.or.jp/EFDB/main.php. Accessed 08.11.2018

A second limitation of SOSTARE for the quantification of greenhouse gas balances of climate smart agriculture practices is that the land use indicators focus on land use diversity and connectivity. A land use indicator relevant for CSA should instead focus both on land use areas and on land use structure. Particularly, the area of permanent pasture and woody vegetation on a farm or in a region is relevant. At farm level, an overall figure of woody vegetation is available in the FADN database. The Dutch parcel registration system includes a wide variety of permanent natural / woody elements that can be considered. At European scale, the density of line and point of natural elements in agricultural land can be derived from LUCAS. When these farm level data or regional data on land use / land cover are combined with emission factors from literature and the IPCC emission factor database[6], this allows the calculation of simple farm level.

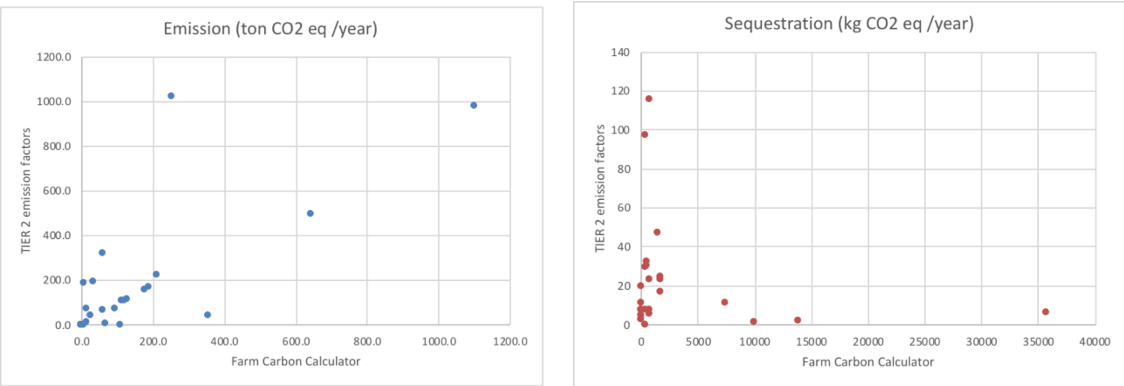
2.3.4 Comparison of farm level tools

Large data gaps hampered a quantitative comparison between FCC and LC-Farm. Both tools include and omit different components of the full greenhouse gas balance. Therefore, considerably different results between the two tools can be expected. The FCC calculates a more detailed and more comprehensive account of carbon sequestration than LC-Farm and does explicitly consider agrochemicals, whereas LC-Farm is more detailed on management practices, includes GHG emission related to cooling, and considers organic matter exchange with other farms. Although the tools both include livestock herd size, manure production, and feed and forage usage, the activity data required considerably differ between the tools, as can be derived from Annex 1: Evaluation of Farm Carbon Calculator tool inputs and Annex 2: Evaluation of LC-Farm inputs. Differences in the topics addressed or omitted and hence, data required by the tools are largely driven by the initial scope for which the respective tools were developed. FCC focused on organic farms in England, which explains the strong attention for soil organic matter management, the focus on specific land systems, and the limited options for crop and management systems. LC-Farm strived for a carbon tool that was applicable for as many different farm types across the whole EU territory. Consequently, a wider variety of practices was relevant to quantify. The LCA-based setup of the tool introduced a product focus, which brought up the inclusion of yield, production quantities and quality indicators, and a much wider range of materials and equipment.

Reason for the large data gaps is that both tools were meant to allow farmers to investigate their own greenhouse gas balance and to act themselves. Consequently, many of the data required do not fall under a reporting obligation. If tools with a level of thematic detail comparable to FCC and LC-Farm would be desired by the Commission, regulations regarding data sharing and harmonization have to be set.

With the spatial and statistical data that is currently, or shortly, available at EU level, complete farm level carbon accounts cannot be calculated.

Figure 5: comparison of emission(left) and sequestration (right) calculated with the farm carbon calculator (x axis) and alternative data (y axis)



A comparison against the Farm Carbon Calculator results demonstrates a good consistency of emission estimates, while sequestration estimates deviate strongly (Figure 5; Table 9). A main reason is that the farm carbon calculator does not include carbon sequestration in permanent grasslands. As in many regions, including the Netherlands, permanent grasslands are a main area for carbon sequestration, this is a considerable gap in the Farm Carbon Calculator. On the emission side, livestock related emissions cover >99.5% of the emission of each farm. In both tools, for this specific set of farms emission is approximately 1000 times higher as sequestration (See Figure 6).

Figure 6: sequestration / emission ratio for 25 sample farms

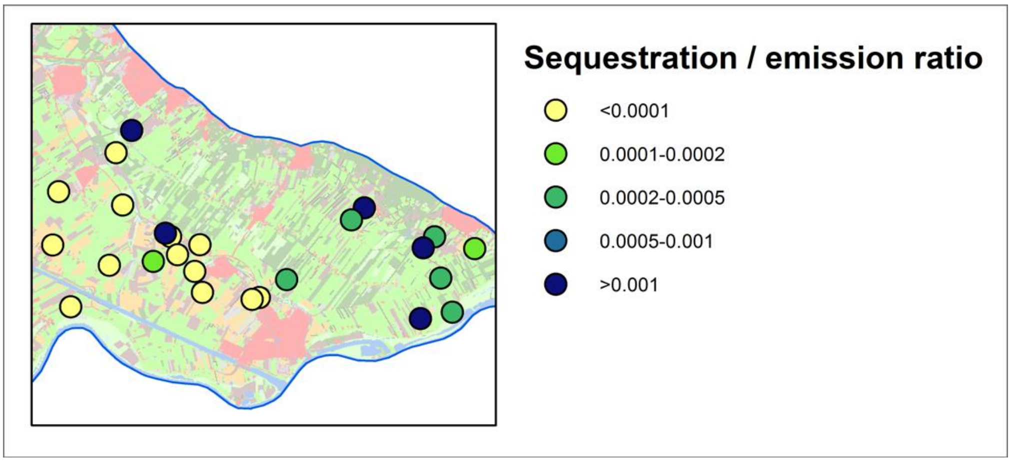


Table 9: Emission and sequestration for 25 sample farms, using the Farm Carbon Calculator tool and country-specific emission factors

	FCC		Tier 2	
FARMID	emission (ton CO_2 eq per year)	sequestration (kg CO_2 / year)	emission (ton CO_2 eq per year)	sequestration (kg CO_2 / year)
1	24.8	314	41.0	97
2	189.9	388	172.3	7
3	212.2	7340	222.3	12
4	7.8	0	186.0	5
5	35.2	675	196.8	5
6	60.0	697	322.1	23
7	252.7	1665	1025.1	24
8	113.5	330	109.5	30
9	121.0	1469	108.7	47
10	68.7	0	6.2	19
11	61.9	428	66.1	32
12	14.8	682	73.2	8
13	111.2	22	2.3	8
14	95.1	1695	75.2	17
15	641.6	660	497.8	116
16	6.5	30	2.2	11
17	15.6	330	15.3	0
18	175.9	420	159.5	30
19	126.8	0	116.4	3
20	354.1	8	41.7	3
21	1100.0	1687	978.5	23
22	0.0	22	0.0	8
23	0.0	13860	0.0	3
24	1.4	35640	0.0	6
25	0.0	9900	0.0	2
Total landscape scale balance	**3790.5**	**78262**	**4418.2**	**539.9**

2.4 Results: Regional-scale tools

2.4.1 EX-ACT tool: Case Friesland

Table 10 provides an overview of the data needs and data availability for the EX-ACT tool. A full overview is given in Annex 3: Evaluation of EX-ACT tool inputs.

Table 10 broad overview of data requirements, data sources, and data availability for EX-ACT

Data category	Broad description of inputs required	Overview of data sources	Data availability (indicators with sufficient data / total indicators in category) (numbers)
Project information	World region, climate and soil condition, project duration	Common knowledge and boundary setting	5 / 5
Land use change	Deforestation and afforestation type and area, forest yields, fire use, other land use change	Corine Land Cover, MODIS, Eurostat data, other European-scale spatial data	7 / 7
Crop production	Changes in crop systems, implementation of specific climate smart practices, yields	Eurostat data, MODIS, other European and global-scale spatial data	6 / 14
Grassland and livestock	Level of degradation, yields, livestock herd size, implementation of specific climate smart measures	Eurostat data, MODIS, other European and global-scale spatial data	13 / 18
Forest degradation and management	Degradation level, area, implementation and extent of specific management practices	Eurostat data, Corine land cover, other European scale spatial data	14 / 24
Coastal wetlands	Area and management of different wetland types	Corine land cover and other European scale spatial data, but facing data limitations	5 / 8
Inputs and investments	Extent and use of fertilizers, pesticides, electricity, fuel, irrigation, buildings and roads	Although several Eurostat indicators provide a reasonable approximation, scale mismatches cause a data shortage.	21 / 34

The EX-ACT tool can calculate emissions origination from land use changes and crop changes at a Tier 1 level with a reasonable reliability. Several of the data can be derived directly, at the right scale, from existing data sources. A major uncertainty is introduced by the focus on degradation which does not fully match the available data. Although approximations of degradation levels can be made using a combination of existing spatial data and expert knowledge, this does introduce uncertainty. Livestock emissions can only be calculated from the livestock itself and from dairy products. The data required to calculate emissions from the production of livestock products other than dairy are not available. Degradation related emission and emissions related to management and investment are very uncertain.

A limitation of EX-ACT is that it disregards a considerable part of the available data on land use change. At European scale, at a NUTS2 resolution, gross change data is available for a wider range of land use and land covers, and shortly forthcoming Sentinel products will further enhance data availability for this purpose. The level of degradation, on the other hand, is poorly defined and is difficult to map at a larger scale. Forthcoming Sentinel products are not expected to solve this. Although the EX-ACT tool quantifies emissions, overall uncertainties are deemed too large to provide a useful picture at regional scale.

2.5 Conclusions and recommendations

Task 2a of this study evaluated the potential to calculate GHG balances or CSA uptake, at farm level and regional level, using available data and using existing carbon tools. To do so, carbon tools were applied to a region, set of regions, or farm, or set of farms. Initially, two farm level tools and one regional level tool were evaluated. Based on data availability issues that became obvious during tool testing, a third tool was tested that has a broad, potentially multi-scale scope.

Carbon tools generally need data on land cover and land use, soil management, livestock, manure management and use of fertilizers, energy use, use of pesticides, irrigation practices, and materials and buildings. Carbon tools generally require very specific indicators for each topic that is quantified. The choice of unit and means of quantifying the topics is generally driven by either the availability of emission factors or by the applicability and monitoring possibilities at farm level. While EU and national statistical datasets have ample data available on the topics accounted for in farm level carbon tools, the data are often not in the right unit required for tool calculations and often thematic resolutions do not match.

The FADN and FSS datasets provide a good set of basic background data and provide insight in many land use and land cover related topics. Tools do however regularly need some spatially explicit data. Spatially explicit data is required to track land cover, land use, and management changes, and to identify management of organic soils. Additionally, some tools require yield data. Regular surveys that include yields are performed, resulting in the availability of annual yield data at NUTS2 level. These datasets have many data gaps, with among others data largely lacking for Germany.

Altogether, the tool evaluation demonstrated that full carbon accounts at farm level cannot be calculated with existing farm carbon tools and available statistical data. Upon quantifying the level of implementation and the potential for further implementation of the full range of CSA practices, a considerable data collection effort is needed. While for example enteric fermentation and decreasing direct emissions from soils have a large potential to contribute to climate change mitigation, quantification of the potential as well as the achievements of the measures requires harmonized EU-level data on topics currently not monitored (e.g. feed quality for enteric fermentation) as well as improved quantification of the empirical relations between the measure and the effect.

As indicated in Task 1, Sentinel derived land cover and land use data, and data on biophysical characteristics provide a large potential for calculating detailed farm level carbon accounts and for identifying climate smart practices. First, crop maps allow more detailed assessment of emissions from arable land.

Experimental high-resolution crop maps for the Netherlands[53] or crop rotation maps for case studies in the UK[54] allow better identification of the exact types of crops grown, which can be used to improve greenhouse gas accounts but also the conversion to more water efficient crops as adaptation measure. Grassland management and vegetation quality maps[55] allow a wall-to-wall identification of grassland, which can help overcome regional data gaps. New soil water products[56] can aid quantifying the effectiveness of adaptation measures. When up and running, these data products could provide a short revisit time, allowing for an up-to-date quantification of practices. Currently, the unaligned revisit times of different datasets hamper up-to-date quantification of climate smart agriculture.

[53] European Space Agency, 2018: Sentinels modernise Europe's Agricultural policy. Available at: https://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinels_modernise_Europe_s_agricultural_policy. Accessed 6.11.2018.

[54] Centre of Ecology and Hydrology, 2018: First ever UK digital crop map satellite data. Available at: https://www.ceh.ac.uk/news-and-media/news/first-ever-uk-digital-crop-map-satellite-data. Accessed 09.10.2018

[55] Sen4camp, 2018: Available at: http://esa-sen4cap.org/content/eo-products. Accessed 03.01.2019

[56] e.g. https://www.nasa.gov/feature/2018/goddard/new-nasa-soil-moisture-data-spots-droughts-floods

3. Task 2b: evaluation of measure uptake

3.1 Introduction

The second part of task 2 concerned quantification of results, uptake, and potential of CSA measures at a European level. Building on the CSA measure inventory and data inventory of Task 1 as well as the potential and limitations of the evaluated carbon tools, a series of quantification steps was taken. First, the current task collected and analysed data on internet access across Europe because farm internet access is deemed essential for monitoring uptake. Secondly, the evaluation of data and tools demonstrated the availability of a wide range of data that might provide insight in CSA uptake, potential, or results, but also indicated that existing carbon tools do not use existing data in an optimal way. For topics other than land use and livestock, detailed data are required that are not available, while for land use and livestock thematic data requirements does not match existing data. Therefore, CSA results and implementation were mapped and quantified with available data. A remaining potential for further CSA calculation was quantified in terms of area, number of farms, and carbon emission reduction.

3.2 Methods

3.2.1 Internet access

By 2017, 87% of EU households had access to the internet, with broadband access being by far dominant. Access differs between 97% of the households in the Netherlands, and 67% in Bulgaria[57]. Little spatial data on internet access is available, however. Available data sources covering the whole EU territory were combined to provide an as detailed as possible picture.

The most detailed statistical data on internet access originate from Eurobarometer surveys, where, most recently in 2016, internet access was surveyed. In each EU country, 1000 respondents were surveyed and the data (accessed through the Eurobarometer Data Service[58]) contain information on respondent's NUTS2 region, level of urbanization, and means of accessing the internet. Data was summarized into percentage of respondents with internet access in each NUTS2-Urbanization degree combination. This was coupled to a NUTS2 map, which was next intersected with a map of the degree of urbanization[59].

A second proxy for internet access, that is however not at the person level but at the location level, is the density of interaction through the internet. People are active on the internet in multiple ways, and over the past years the density of photo uploads to platforms such as Panoramio or Flickr have gained prominence as indicators for the value people

[57] Europa.eu 2018: Digital economy and society statistics. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php/Digital_economy_and_society_statistics_-_households_and_individuals#Internet_access. Accessed 13.12.2018

[58] Gesis.org. 2018: Eurobarometer special edition 438, survey wave 84.2. Available at: https://www.gesis.org/eurobarometer-data-service/home/; Accessed 20.12.2018

[59] Lewis Dijkstra and Hugo Poelman, 2014: A harmonised definition of cities and rural areas: the new degree of urbanisation, Available at: http://ec.europa.eu/regional_policy/sources/docgener/work/2014_01_new_urban.pdf

attach to landscapes (Van Zanten et al. 2016[60]). At the same time, the fact that people are able to upload photos to Panoramio also proves the availability of mobile internet. A shortcoming of this proxy is that people might upload on another location than where the photo is taken.

A map of Panoramio photo density (Tieskens et al., 2017[61]) was used as a proxy for internet access. The map was aggregated to the spatial units of the internet access – degree of urbanization intersection and systematically compared.

3.2.2 Current CSA outcomes

To obtain an overview of the CSA status of the EU territory, a data harmonization step was performed and three groups of indicators were developed.

First, an inventory of CSA outcomes based on the SOSTARE tool was developed. Using LUCAS data and FADN data (details in the excel annex), the SOSTARE input categories relevant to climate smart agriculture (Carbon tools 2.3.3) were quantified at NUTS2 resolution. Second, livestock activity data were collected from FADN and additional land use indicators, i.e. percentage of farm woodland, were collected from LUCAS and aggregated to NUTS2. As a third step, emission factors for land use, livestock, and energy were collected, from the EX-ACT tool, Schulp et al. (2008)[62] and the IPCC emission factor data base (all data in the excel annex) and combined with the aforementioned activity data to calculate an EU level carbon balance.

As a second output, an index that closely follows SOSTARE but focuses on climate smart agriculture was developed. The index includes the SOSTARE categories "Cropping system", "Water management", and "Land use" and exactly follows the indicator calculation and weighting, but adds an indicator for livestock greenhouse gas emissions, similar to the indicator described above. Indicators included in this index are summarized in Table 11 and calculation details can be tracked in the R tool (see Annex 6: Data Annex).

A third output is another semi-quantitative indicators for climate smart agriculture. As reduction of greenhouse gas emission is not the only climate smart agriculture action that contributes to mitigation, also the spread of e.g. irrigation practices that are more energy efficient is of relevance. Furthermore, mitigation alone is deemed insufficient to deal with climate change[63] and adaptation efforts are necessary. This includes, among others, the use of cover crops to deal with increased erosion under increased frequency of precipitation peaks, the use of more water efficient irrigation methods, and the use of linear and point natural elements to provide shade. Altogether, based on inputs from LUCAS and FADN a set of indicators was made following the SOSTARE approach (Paracchini et al. 2015[64]), that were summarized into a map of the level of implementation of mitigation and adaptation practices compared to the European average. Indicator definition and calculation, as well as aggregation into indices for each SOSTARE category, exactly follow the approach and indicator weights specified in Paracchini et al. (2015). Table 11 lists the indicators used.

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[60] Van Zanten et al. 2017: Continental-scale quantification of landscape values using social media data, Proceedings of the National Academy of Science. DOI: 10.1073/pnas.1614158113

[61] Tieskens et al. 2017: Characterization of European Cultural Landscapes: accounting for structure, land use intensity and value of rural landscapes, Land Use Policy 62C:29-39.

[62] Schulp et al. 2008: Future carbon sequestration in Europe - Effects of land use change, Agriculture, Ecosystems & Environment 127(3-4): 251-264.

[63] UNFCC, 2018: The Paris Agreement. Available at:https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement. Accessed at 13.12.2018.

[64] Paracchini et al. 2015: A diagnostic system to assess sustainability at a farm level: The SOSTARE model." Agricultural Systems 133: 35-53

It should be noted that both semi-quantitative indices build closely on the principles and indicators deemed important in SOSTARE and are restricted by the availability of European-scale data. With that, they provide a broad picture of the spatial patterns of CSA practices, as well as in impression of which level of mapping and quantification is feasible with existing data and indices, rather than an exact quantification.

Table 11. Indicators for the construction of CSA indices

Indicator	Source	SOSTARE category	SOSTARE code	SOSTARE weight	Mitigation / adaptation
% area with multi cropping	LUCAS	Cropping system	A19	1	Adaptation
% area leguminous crops	LUCAS	Cropping system	A20	1	Mitigation
% area with a winter Crop cover	LUCAS	Cropping system	A21	0.5	Adaptation
% area Permanent grassland	LUCAS	Cropping system	A22	0.5	Mitigation
% area not conventionally ploughed	LUCAS	Cropping system	A91	0.5	Mitigation
% area with crop residues left on the field	LUCAS	Cropping system	A92a	1	Mitigation
% area irrigated	LUCAS	Water management	A49	0.33333333	Adaptation
% Irrigation with Energy	LUCAS	Water management	A50	0.33333333	Adaptation
% Irrigation with Groundwater	LUCAS	Water management	A51	0.33333333	Adaptation
% area with Linear Elements	LUCAS	Land use	L01	0.35	Adaptation
% area with Natural Point Elements	LUCAS	Land use	L03	0.15	Mitigation
% area with woodland in agricultural area	FSS	Land use	n/a	0.5	Mitigation
Livestock overall	FSS	Livestock	n/a		Mitigation

3.2.3 Measure uptake

Task 1 identified 41 CSA measures, that have the potential to contribute to climate change mitigation by reducing emissions, enhancing sinks, or offsetting fossil fuel use, or could contribute to climate change mitigation. The measures were classified as having the potential to be implemented at farm level versus needing regional coordination, as well as according to affecting the land use structure versus affecting the agronomic structure of the farm or region (Weltin et al., 2018[65]). Furthermore, we judged if each measure contributed to mitigation, adaptation, or both, and we reasoned out for which farm types

[65] Weltin et al. 2018: Conceptualising Fields of Action for Sustainable Intensification – A Systematic Literature Review and Application to Regional Case Studies, Agriculture, Ecosystems & Environment 257:68-80.

the measure would be applicable. Table 12 provides an overview of the scope of the measures identified.

Table 12: Overview of scope of CSA measures as inventoried in Task 1

Classification criterion	Number of measures
Scale and field of application	
Farm scale – Structure	25
Farm scale – Land	23
Region scale – Structure	3
Region scale – Land	7
Mitigation / adaptation	
Mitigation	30
Adaptation	17
Farm type	
Specific crop or livestock system	3
Cropland	7
Livestock	9
Land-based	15
Generic	6

Numbers in different classification criteria can sum up to larger numbers than the total number of measures (41) because some measures have a dual scope or effect.

As a next step, we evaluated the data availability for quantifying and monitoring uptake and effectiveness of the measures. We compared the list of measures with the data overview also created in Task 1, and cross checked if the available data provided possibilities for quantification. Based on the cross check, it was found that 10 of the measures could be easily quantified at farm level using FADN based indicators: Use of cover crops, use of catch crops, perennial grasses, permanent crops, bioenergy crops, deep rooting crops, agroforestry, afforestation / reforestation / woodland planting, and biological N fixation. We quantified current uptake of these 10 measures. We analysed the measures individually and did not consider overlap between different measures.

Use of cover crops was quantified based on the presence of peas, beans, pulses, rye, grassland, brassica, or other fodder plants. The measure was assumed applicable for land-bound farms.

Use of catch crops was quantified based on the presence of rye or brassica species and was also assumed applicable for land-bound farms.

Perennial grasses were quantified based on the presence of permanent grasslands. It was assumed that all farms that have grasslands within their UAA can take up the measure.

Permanent crops were quantified based on the presence of fruit, olives, vines, or orchards on the farm. While this measure obviously applies to permanent crop specialist farms (TF35, 36, 38), uptake of the measure might be an option for all land-bound farms.

Bioenergy crops are specifically inventoried as a separate category in the FADN. The measure was directly quantified based on the presence of this category and the measure was evaluated feasible for all land-bound farms.

Deep-rooting crops comprise rape seed, sunflowers and sugar beets, and other crops that are not distinguished in FADN. The measure was quantified based on the presence of these three crops and was assumed applicable for all land-bound farms.

Agro-forestry is difficult to identify with certainty. However, an approximation can be made by inventorying if farms grow both permanent crops and field crops, and by comparing the total harvested area with the farm UAA. If the harvested area is larger than the farm UAA, the farm will do double cropping practices that might be considered agroforestry, although this cannot be confirmed with certainty. The measure is assumed applicable for land-bound farms.

Afforestation, reforestation and woodland planting can be a process that happened in the recent past as well as a currently ongoing process. The presence of woodland on a farm as recorded in FADN is considered an indicator for the former, subsidies for woodland as part of the farm financial balance is considered an indicator for both the former and the latter. The measure is assumed applicable for all land-bound farms.

Biological N fixation was quantified based on the presence of peas, beans, other pulses and brassica species. The measure was assumed applicable for land-bound farms.

For each measure, using an R tool (added as supplementary material) the farms for which the measure is applicable were selected. Farms where the measure was implemented were identified based on the criteria described before, and the total number of farms where the measure was implemented was quantified at NUTS2, country, and European level. This number was compared to the total number of farms where the measure could be implemented. The ratio of farms that implemented the measure to the number of farms that could was exported to a NUTS2 level shapefile, and tables of the level of uptake overall were created.

The exact FADN variables used for quantification are documented in a supplementary table.

3.2.4 Potential for measure uptake

Implementation of CSA practices can require a modest or a considerable change of farming practices. Uptake of new farming practices has been extensively researched and is frequently related to the *willingness* to adopt and the *ability* to adopt (Mills et al., 2017[66]; Valbuena et al., 2008[67]; Zagaria et al., 2017[68]). Willingness and ability to adopt are influenced by farmers age, education level, farm size, and tenure. Farmers open to innovation and adoption of sustainable practices tend to be younger, be better educated and have larger farms (Genius et al., 2006[69]; Passel et al., 2007[70]; Koesling et al., 2008[71];

[66] Milles et al, 2017: Engaging Farmers in Environmental Management through a Better Understanding of Behaviour," Agriculture and Human Values, Journal of the Agriculture, Food, and Human Values Society ,34(2), pp. 283–299.

[67] Valbuena et al 2008: A Method to Define a Typology for Agent-Based Analysis in Regional Land-Use Research", Agriculture, Ecosystems and Environment 128(1–2):27–36.

[68] Zagaria et al. 2017: Cultural landscapes and behavioural transformations: An agent-based model for the simulation and discussion of alternative landscape futures in East Lesvos, Greece. Land Use Policy 65: 26-44. doi: 10.1016/j.landusepol.2017.03.022.

[69] Genius et al. 2006: Information acquisition and adoption of organic farming practices, Journal of Agricultural and Resource economics, 93–113.

Genius et al. 2006: Information acquisition and adoption of organic farming practices. Journal of Agricultural and Resource economics, 93–113.

[70] Passel et al. 2007: Measuring farm sustainability and explaining differences in sustainable efficiency. Ecological Economics 62 (1), 149–161.

[71] Koesling et al. 2008: Factors influencing the conversion to organic farming in Norway, International Journal of Agricultural Resources, Governance and Ecology 7 (1-2), 78–95.

Lobley et al., 2009[72]; Gómez-Limón et al., 2010[73]; Zagata et al., 2015[74]; Pavlis et al., 2016[75]). The type of tenure is important because farmers tend to adopt more sustainable practices on owned land than on rented land (Fraser, 2004[76]). If farmers own the land, they are more willing to invest and to participate in agri-environmental schemes (Walford, 2002[77]). Economic reasons, specifically direct payment, are often seen as an important trigger for the adoption of new practices and is related to both willingness and ability (Papadopoulos et al., 2015[78]; Lastra-Bravo et al., 2015[79]; Pavlis et al., 2016, Siebert et al., 2006[80], Mills et al., 2017). The availability of certification schemes has been demonstrated to increase farmers environmental engagement (Papadopoulos et al., 2015). Furthermore, full uptake is not feasible because conflicting with other farm goals. Although these factors influencing uptake are well known and well understood, it is impossible to set a standard benchmark or target that quantifies which farmers can reasonably adopt a measure, and to which extent. We therefore explored the potential for uptake using a theoretical, top-down approach, however exploring different benchmark levels. This provides insight in a maximum potential. We adopted a four-step approach for quantifying the potential.

1. Stratification: farms within Europe vary in biogeographical background and in historic and socio-economic context. These factors strongly influence the farm structure and constrain the opportunities for uptake of CSA measures. As a first step, we stratified farms to generate groups that were assumed more or less homogenous with regard to biogeographical conditions and socio-economic context. We assumed that the intersection between country and biogeographical region provided sufficiently homogenous groups. Countries approximate the socio-economic background, environmental regions stratify by biophysical constraints including climate, geomorphology, oceanicity, and latitude. The environmental regions map of Metzger et al. (2005)[81] was adopted, using the higher-level classification that distinguishes 13 environmental zones (Figure 7). (2005)[82] was adopted, using the higher-level classification that distinguishes 13 environmental zones (Figure 7). The biogeographical region map was intersected with a country map in GIS, and a dominant biogeographical region was attributed to each NUTS2 region (Figure 8).

2. Benchmark: for each CSA practice, we calculated the median level of implementation in each country-biogeographical region stratum. We assumed that the median was a suitable benchmark, i.e., each farm that could logically adopt a specific practice could do so as to a level of the median in its stratum. Practice

[72] Lobley et al. 2009: The contribution of organic farming to rural development: An exploration of the socio-economic linkages of organic and non-organic farms in England. Land Use Policy 26 (3), 723–735.

[73] Limon et al. 2010: Empirical evaluation of agricultural sustainability using composite indicators. Ecological Economics 69 (5), 1062–1075.

[74] Zagata, L., Sutherland, L.-A., 2015: Deconstructing the 'young farmer problem in Europe': Towards a research agenda, Journal of Rural Studies 38, 39–51

[75] Pavlis et al. 2016: Patterns of agrienvironmental scheme participation in Europe: Indicative trends from selected case studies. Land Use Policy 57, 800–812.

[76] Fraser, E.D., 2004: Land tenure and agricultural management: Soil conservation on rented and owned fields in southwest British Columbia, Agriculture and Human Values 21 (1), 73–79.

[77] Walford, N. 2002: Agricultural adjustment: adoption of and adaptation to policy reform measures by large-scale commercial farmers. Land Use Policy 19 (3), 243–257

[78] Papadopulos et al. 2015: Going Sustainable or Conventional? Evaluating the CAP's Impacts on the Implementation of Sustainable Forms of Agriculture in Greece," Land Use Policy , 47(4), pp. 90–97.

[79] Lastra-Bravo et al. 2015: What drives farmers' participation in EU agri-environmental schemes?: Results from a qualitative meta analysis, Environmental Science & Policy , 54 , 1-9.

[80] Siebert et al. 2006: Factors Affecting European Farmers' Participation in Biodiversity Policies," Sociologia Ruralis , 46(4), pp. 318–340.

[81] Metzger et al. 2005: A climatic stratification of the environment of Europe." Global Ecology and Biogeography 14(6): 549-563.

[82] Metzger et al. 2005: A climatic stratification of the environment of Europe." Global Ecology and Biogeography 14(6): 549-563.

implementation and benchmarks were calculated as the percentage of the farm UAA dedicated to the specific practice.

3. Compare farms with benchmark: for each farm, the level of implementation expressed as the percentage of area dedicated to the specific practice was compared with the benchmark. If a farm was above the benchmark, we assume that no additional implementation of the measure would be realistic. If a farm was below the benchmark, we assume that it could increase the UAA % dedicated to the practice to the benchmark level. Based on this assumption, we calculated, for each farm, the potential extra area that could be attributed to each practice.
4. Farm level areas were upscaled to NUTS2 using the number of farms represented by each sample farm (SYS02).

Additionally, a sensitivity analysis was done by applying the methodology with different benchmarks. As far as data allowed (Table 1), the uptake potential was calculated in terms of potential carbon sequestration. CAP Greening requirements and funding were compared with the potential in order to support the discussion on the feasibility of implementation.

The model code for performing the calculations as well as a brief documentation can be found in Annex 7: Model Code and Documentation

Figure 7: environmental zones according to Metzger et al. (2005).

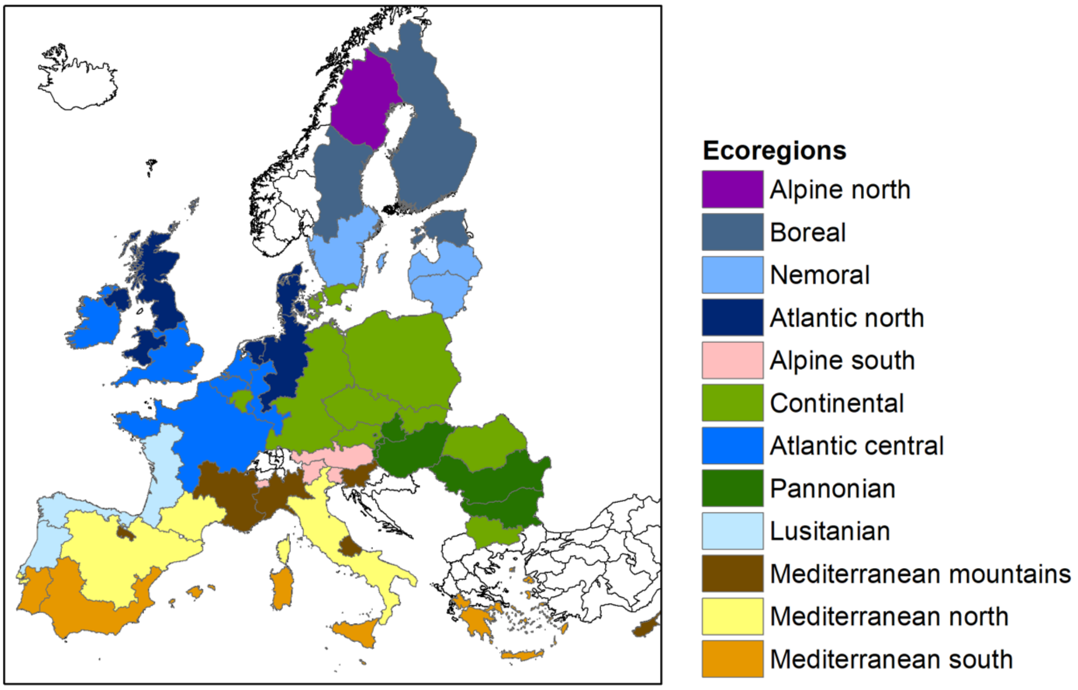
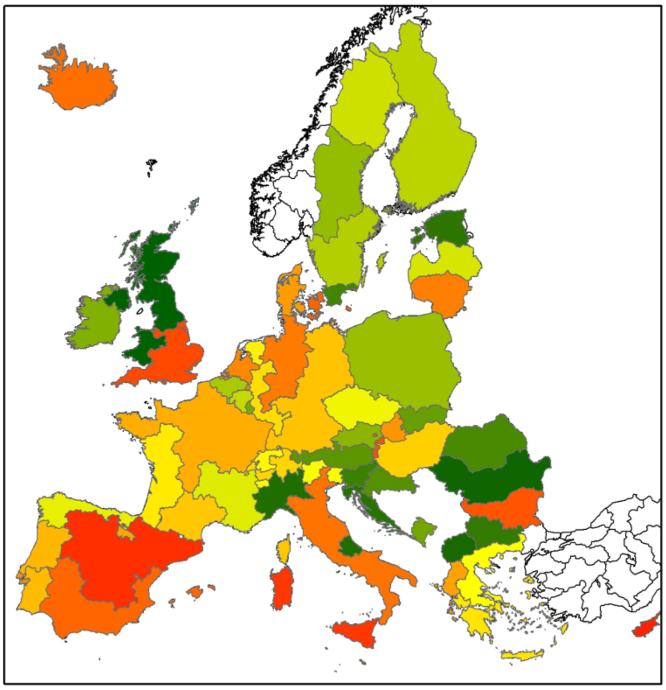


Figure 8: Intersection of countries and environmental zones, resulting in strata for evaluating measure implementation. Strata are shown in different colours for the sake of clarity.



3.3 Results

3.3.1 Internet access

Figure 9 shows that internet access in Europe strongly varies between rural and urban areas. While in urban and peri-urban regions commonly over 80% of the population appears to have regular internet access, in rural areas of Hungary, Bulgaria, and Spain figures between 43% and 50% are seen.

Figure 9. Percentage of Eurobarometer respondents with internet access.

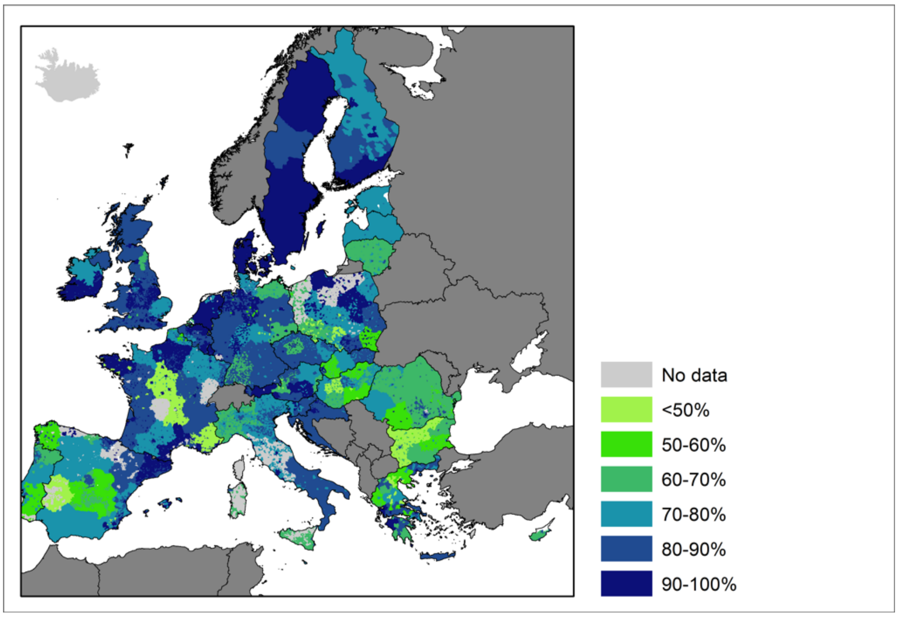


Figure 10. Panoramio upload density. Based on Tieskens et al. (2016)

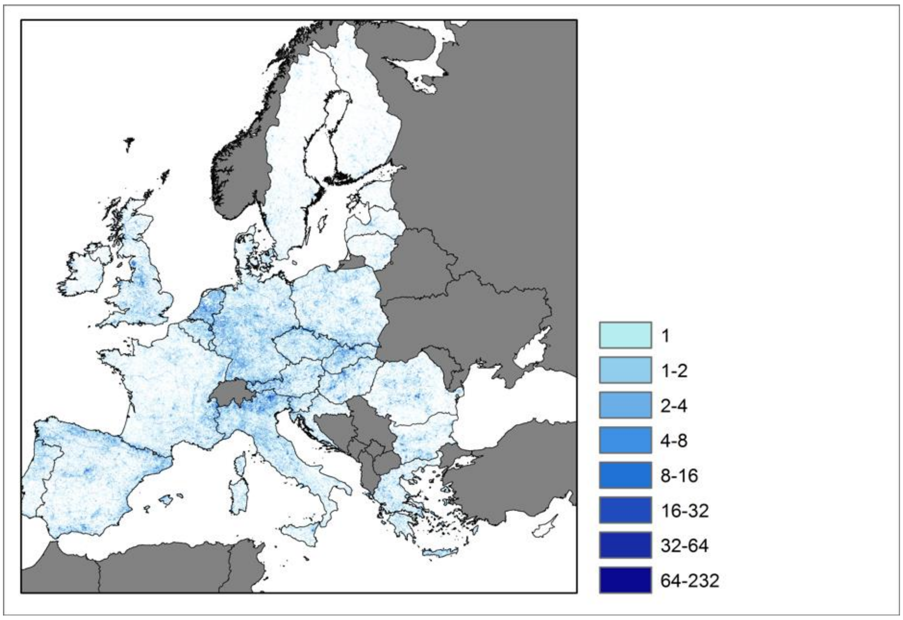


Figure 10provides a finer-grain approximation of internet access, through showing the density of photo uploads to Panoramio. High densities are seen in the northwest of Europe, as well as in many mountainous regions. Although the photo density is biased towards tourist attractions and might be influenced by differences between the location where the picture is taken and the location of uploading to Panoramio, it does demonstrate widespread availability of internet access throughout Europe. This is also demonstrated by Table 13.

Table 13. Area percentage with photo uploads.

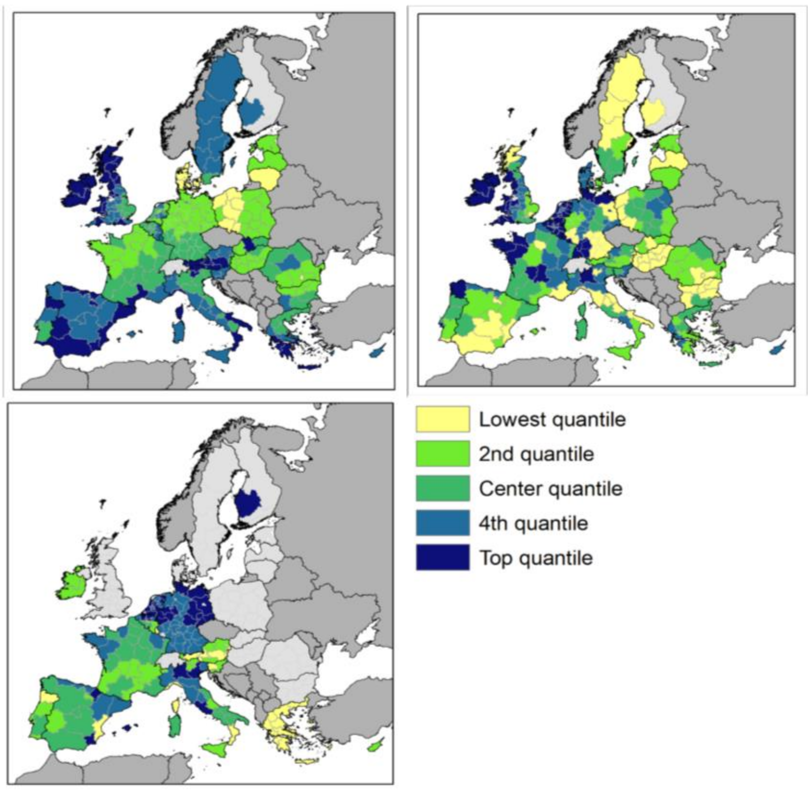
Country	Percentage area with >1 photo upload per km^2
Austria	28.7%
Belgium	29.0%
Bulgaria	13.1%
Czech Republic	30.9%
Denmark	17.5%
Estonia	4.2%
Finland	2.3%
France	13.4%
Germany	31.3%
Greece	23.7%
Hungary	22.3%
Ireland	9.4%
Italy	27.8%
Latvia	7.6%
Lithuania	7.1%
Luxembourg	34.1%
Malta	82.6%
Netherlands	56.8%
Poland	18.3%
Portugal	17.0%
Romania	9.9%
Slovakia	35.9%
Slovenia	28.6%
Spain	19.0%
Sweden	3.4%
United Kingdom	19.9%

3.3.2 CSA outputs at European level

As a first output, total greenhouse gas emissions from farming at NUTS2 level were calculated. Separate figures are available for energy, livestock and land. Given considerable data gaps in the energy figures, aggregated estimates are unreliable.

Figure 11 demonstrates the highest emissions from land in southern and western Europe, due to unfavourable soil and / or climate conditions for CO_2 sequestration. Livestock emissions are strongly skewed and are high in the dominant livestock production areas in specific northwest European regions, including the Netherlands. Energy emissions are considerably higher in western Europe than in Eastern Europe. Granivore specialists, dairy specialists, as well as large-scale farms that mix livestock and field crops are energy intensive and energy use increases upon farm size. Consequently, emissions per farm are highest in eastern Germany, where energy intensive farm types of a large size are common.

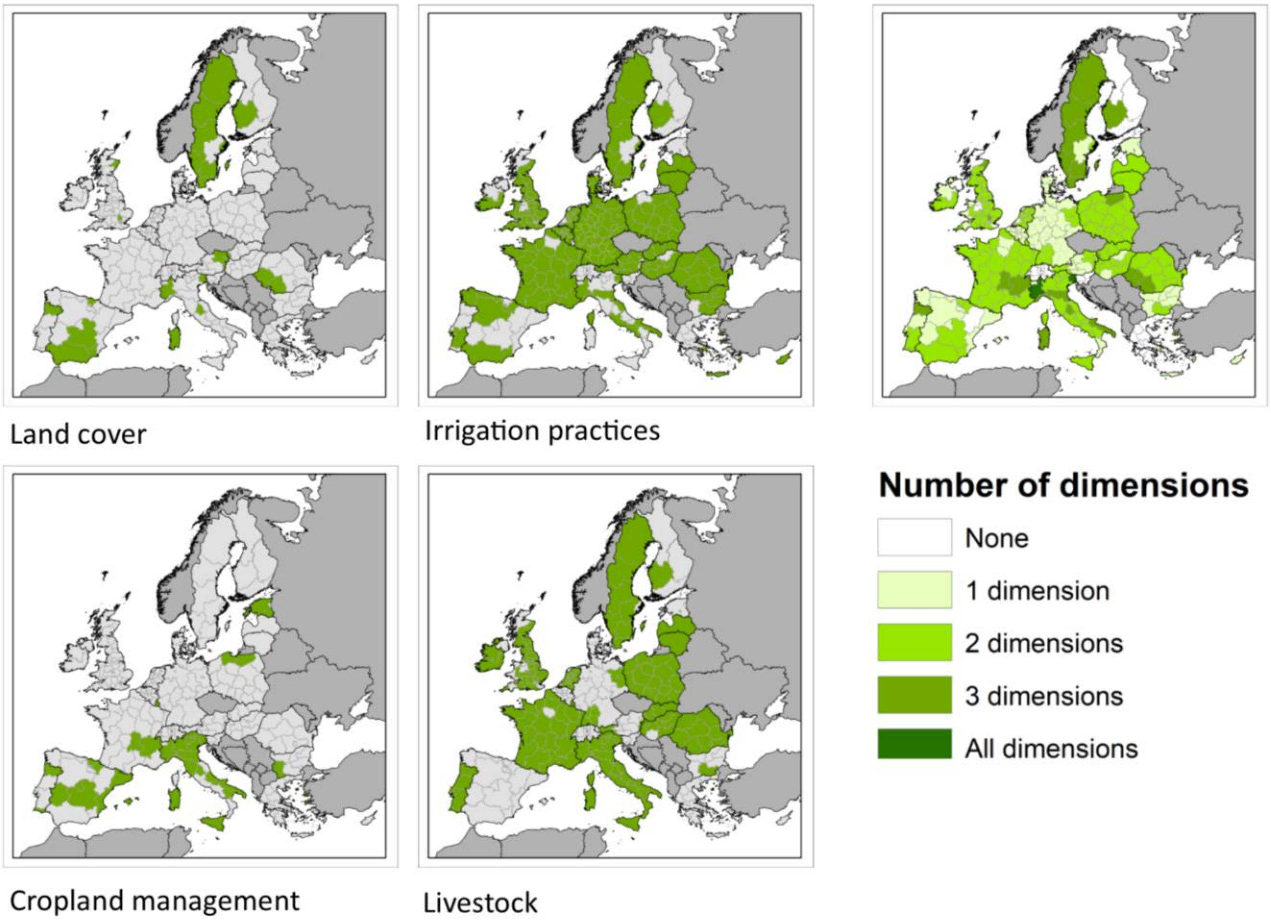
Figure 11. Greenhouse gas emissions in agriculture from land (top left), livestock (top right), and energy (bottom)



Colours indicate five quantiles. Data gaps appear for the light grey regions. Data is in Annex 6: Data Annex

Figure 12 shows that a few regions in northern Italy have the most widespread implementation of climate smart agriculture practices, on cropland management, irrigation, land cover, as well as livestock numbers. A few scattered regions show widespread implementation of three of the four categories while large areas of central Europe demonstrate little implementation of climate smart practices.

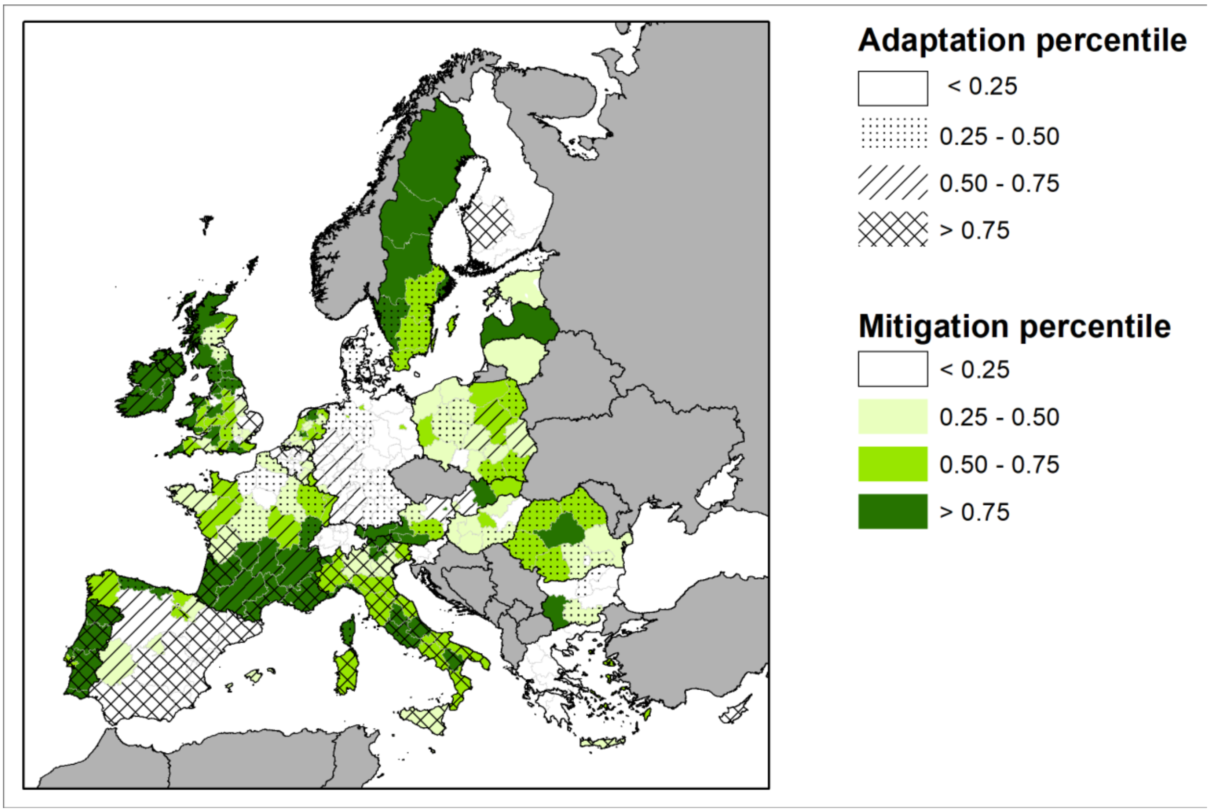
Figure 12. NUTS regions that perform above-median with regard to a selected set of climate smart agriculture practices (left and centre) and overview map of CSA measure implementation (right).



Grey regions have below-median values for all categories; indicator values were not calculated for white regions because of data gaps. The top right map combines the four maps of individual dimensions by counting the number of dimensions for which a region has an above-median implementation level.

Figure 13 summarises the spread of practices along axes of mitigation and adaptation. Here, it can be seen that Italy, western England, Ireland, and Central France and Ireland have widespread implementation of both adaptation and mitigation practices, while in e.g. Spain and Germany the spread of mitigation practices is low. Sweden and Latvia show little implementation of adaptation practices, while mitigation practices are widespread. This mostly concerns farm woodlands.

Figure 13. Spread of mitigation and adaptation practices. Aggregated indicators for both dimensions (see Table 6) are divided into quartiles and combined.



3.4 Measure evaluation

An inventory of the level of implementation of specific CSA measures demonstrates a large potential for further uptake (Table 14, Figure 15, Figure 16)

For bioenergy crops, we assumed that all farms with cropland could include bioenergy crops in their cropping plan, totalling 2.18 million farms represented by the FADN sample. Of these farms, 0.9% (19 thousand) indeed dedicate part of their UAA to biofuels (Table 14), totalling over 4000 km^2. Particularly in the Northern and Southern Atlantic regions (Table 15; 6% and 5% respectively), farms with cropland grow biofuel crops while in the southern Mediterranean and Pannonian regions only small percentages of the farms with cropland do so (Table 15; 0% and 0.009% respectively; more disaggregated spatial distribution shown in Figure 16). We identified another 2160 thousand farms that potentially could grow biofuel crops (Table 14), leaving in total over 70 thousand km^2 for further implementation. Poland is an example country where a high percentage of farms has the potential to adopt biofuel production as a CSA (Figure 14), while the key potential area is found in Poland, the Baltic countries, and France (Figure 15). Available data on the mitigation potential of bioenergy crops did not allow calculating potential greenhouse gas emission savings.

For other CSA measures, uptake percentages are considerably higher, with for example 63% of suitable farms having permanent grassland. When assuming a benchmark of the median area percentage of the farm UAA dedicated to the measure, this leaves a potential area for implementation of measures of up to 637 thousand km^2 for permanent crops, and between 100 and 200 thousand km^2 for most other measures (Table 14). Implementation of woodland or permanent crops has the largest potential in terms of emission savings, but practical constraints upon implementation of these measures are considerable. Furthermore, farm woodland expansion might trade off with food production and farm income, meaning that barriers towards implementation of these measures might be considerable.

Additional data (Numbers of farms that implemented each measure, sensitivity analysis results) can be found in Annex 5: CSA measure implementation.

Table 14: used potential of selected CSA measures (number of farms that implemented the measure as a percentage of the farms that could implement the measure). A benchmark of the median UAA percentage dedicated to the measures within the country-ecoregion was assumed.

Measure	% of potential used (number of farms)	Additional farms where measure could be implemented (thousands)	Potential area for implementation (km^2, 50% benchmark)	Current area (km^2)	Potential emission savings (Mton CO_2 eq / year; range)
Bioenergy crops	0.9%	2160	71258	4018	Insufficient data
Catch Crops	9.8%	2819	143616	20465	12.64 – 21.11
Cover crops	24.7%	2354	127534	77211	11.22 – 18.75
N fixation	36.2%	2264	174926	117498	-3.50 – 12.94
Combining permanent and field crops	18.1%	3658	2504	38240	0.04 – 0.22
Woodland	19.9%	3577	142118	60107	15.63 – 95.36
Deep rooting crops	13.3%	3874	217720	130950	0 – 47.90
Permanent crops	32.0%	3036	637066	95892	0 – 140.15
Permanent grasslands	62.9%	845	201230	280580	22.14 – 44.27

Table 15: used potential of selected CSA measures (farms that implemented the measure as a percentage of the farms that could implement the measure) per ecoregion. A benchmark of the median UAA percentage dedicated to the measures within the country-ecoregion was assumed.

Ecoregion	Combining annual and permanent crops	Biofuel crops	Catch crops	Cover crops	Deep rooting crops	N fixating crops	Permanent grassland	Permanent crops	Woodland
Alpine north	27%	0%	7%	24%	0%	22%	46%	18%	4%
Boreal	4%	0%	5%	24%	9%	7%	21%	2%	6%
Nemoral	10%	0%	9%	32%	6%	8%	25%	6%	15%
Atlantic north	3%	6%	9%	19%	12%	24%	45%	3%	18%
Alpine south	13%	5%	1%	13%	1%	16%	39%	15%	37%
Continental	13%	0%	11%	18%	7%	22%	39%	8%	17%
Atlantic central	3%	2%	1%	19%	15%	21%	48%	5%	7%
Pannonian	17%	0%	1%	5%	8%	14%	15%	11%	1%
Lusitanean	21%	0%	3%	15%	6%	24%	41%	18%	9%
Mediterranean mountains	28%	0%	1%	16%	3%	15%	33%	24%	15%
Mediterranean north	36%	0%	1%	10%	5%	15%	13%	32%	6%
Mediterranean south	24%	0%	5%	4%	1%	14%	11%	38%	1%

Most of the evaluated measures can, based on broad climate and soil conditions and based on farm types, be implemented across Europe. Nevertheless, clear differences in patterns of implementation are obvious across Europe. Table 15 demonstrates a lower uptake of CSA measures in the Pannonian and Boreal regions. Perennial grassland tends to higher implementation percentages. Permanent crops and land use systems at farm level where permanent crops and field crops are combined at farm level are more common in southern Europe. Woodland and catch crops are more common in the eastern part of the EU, while the use of cover crops is widespread throughout the northern part of Europe. Figure 14, Figure 15, and Figure 16 detail the spatial variation of the CSA implementation and potential. The southwest of Europe, and Ireland, appear to have space for agroforestry and permanent crops. Potential for expanding biofuels is particularly found in France, Poland, eastern Germany, and the Baltic countries, as well as in Italy. Scope for expanding woodland, cover crops, catch crops, and deep rooting crops seems to be available throughout Europe, with the exception of Sweden, Netherlands, and Germany. The potential for nitrogen fixating crops is most outstanding in Spain and Romania.

Several of the practices assessed here have multiple effects on climate change mitigation and/or adaptation. For example, nitrogen fixating crops simultaneously improve soil quality and create a soil cover that protects against erosion and floods. Consequently, a large group of farms applies multiple CSA measures. 24% of the farms applies two measures, 12 farms (0.02%) apply eight measures, and only 20% of the farms in Europe have not applied a CSA measure (Table 16). N fixating crops, catch crops, and cover crops are often present on the same farm; there is overlap among the crops that represent these CSA measures. Woodland and combining annual and permanent crops are rarely combined with other CSA measures; they are more commonly applied independently. This is closely related to the types of farming systems that implement these measures. Farms that implemented one CSA measure on average dedicate 58% of their area to CSA practices, while farms with seven or eight measures have CSA practices on average on 96% of their farm area. This also demonstrates that the same area can supply multiple CSA benefits.

Table 16: implementation of multiple CSA measures

Number of measures implemented	% of UAA dedicated to CSA measures	Number of farms (thousands)	Number of farms (% of total)	Average area (ha) per farm dedicated to CSA measures
0	N/A	850	18.5%	N/A
1	58%	1 601	34.9%	1035
2	64%	1 058	23.0%	1300
3	67%	675	14.7%	1294
4	68%	279	6.1%	1520
5	70%	97	2.1%	1734
6	74%	23	0.5%	2179
7	81%	7	0.1%	2743
8	79%	1	0.0%	4722
9	96%	0	0.0%	6681

Figure 14. Unused potential of selected CSA measures: percentage of farms that did not implement the measure as a percentage of the farms that could implement the measure

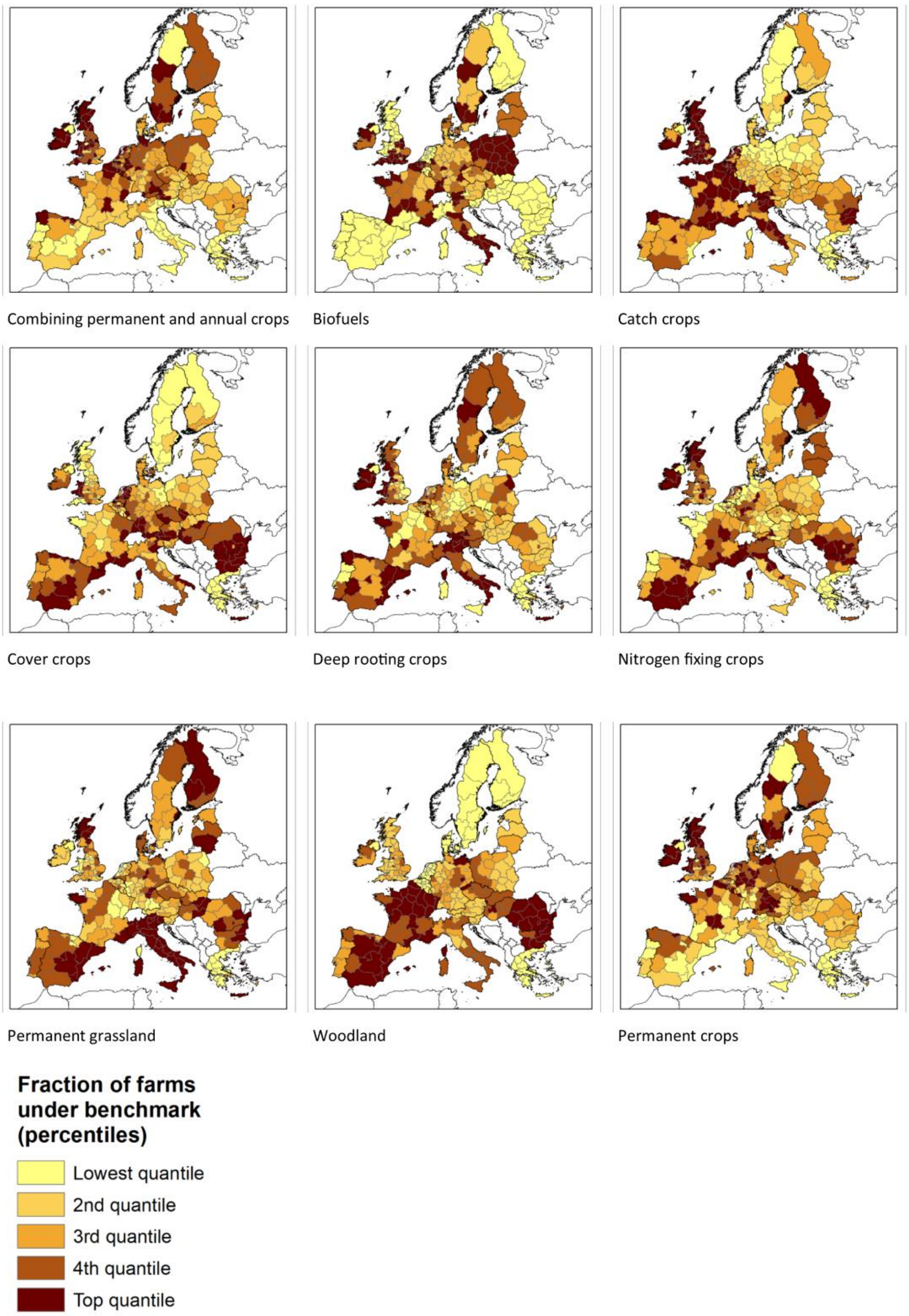


Figure 15: Spatial distribution of potential area of implementation

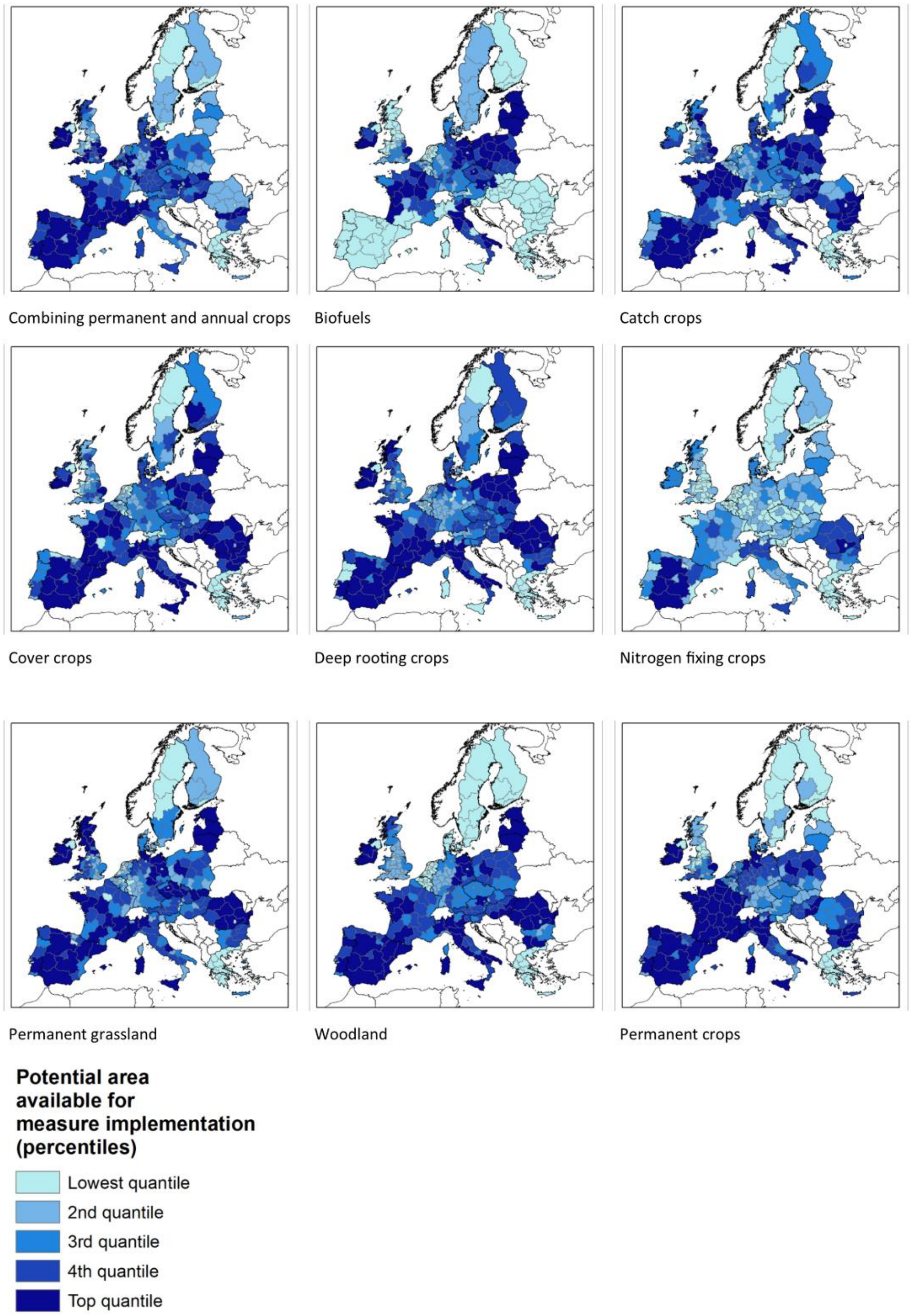
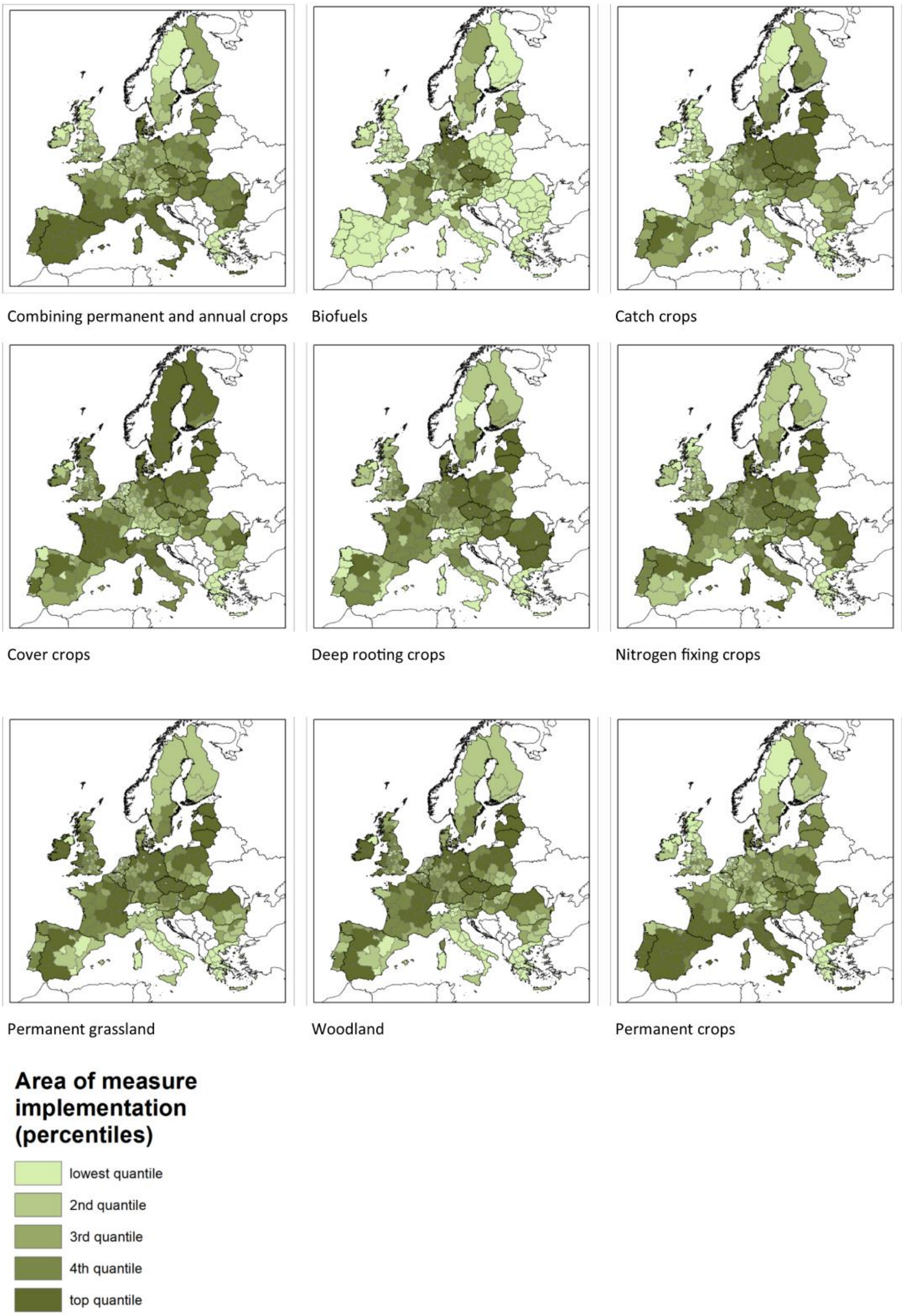


Figure 16: current area of measure implementation.



3.5 Overall findings, discussion, conclusions, and recommendations

Based on FADN data, the level of uptake of a selected set of CSA practices was quantified. Given the available data, focus was on measures that are implemented through area based measures, dominantly changing the crop type. On average, over 80% of farms considered has one or more of such CSA practices in place. Comparison between farms within the same country and ecoregion demonstrated a large scope for further uptake of CSA measures.

Implementation of some of the CSA measures considered are explicitly considered as greening measures in the CAP. This applies for permanent crops as a separate greening measure, while many countries consider catch crops or nitrogen fixing crops eligible as EFA. Afforestation or managing small woodland features can also be considered as EFA or can be supported as a rural development measure[83]. Nitrogen fixing crops and catch crops are EFA types often implemented and reported, with nitrogen fixing crops prevalent in Croatia, Czech, Poland, Romania, and Italy while catch crops are widespread in Belgium, Denmark, Germany, Luxembourg and the Netherlands[84]. Uptake is triggered by economic factors where farmers steer towards cost efficiency, as well as restrictions set by governments.

Upon exploring the potential of CSA measures, we used a simple assumption on the types of farm that could adopt a certain measure. We based this on the types of farming classified into 14 groups (TF14) reported in the FADN database. Furthermore, we implemented a top-down benchmark to define the area percentage of the farm UAA on which a measure could be applied. Although we defined benchmarks specific to biogeographical region – country strata and only used the median area percentage in each stratum as a benchmark, this approach might lead to overestimation of the potential. Actual implementation of measures is hindered by many barriers. These include lack of knowledge on the optimal implementation of the practice, high initial investment, farm dependence on specific purchasers and products, or social resistance.

Furthermore, this study did not consider trade-offs of CSA implementation. Wider implementation might go at the cost of space for food or biomass production and lead to displacement. Finally, we did not calculate the potential of combined implementation of multiple measures. A next research step would be calculation more location specific mitigation potentials to be able to calculate these tradeoffs. Only then, costs and benefits of CSA measures can be weighted and potential funding can be directed.

For a complete evaluation of CSA uptake and effects, specific inventory of the measures is required. For field based measurement this could be included in LUCAS surveys by e.g. inventorying different irrigation systems in more detail. For livestock based emissions, that comprise the largest part of agricultural emissions, it requires specific information on feeding practices and manure management practices. These data have been collected in the 2010 farm census and a repetition if this census might provide relevant data on temporal changes.

[83] Martineau, H., et al. (2016). Effective performance of tools for climate action policy - meta-review of Common Agricultural Policy (CAP) mainstreaming, European Commission - DG Climate Action.

[84] European Commission (2017). REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL on the implementation of the ecological focus area obligation under the green direct payment scheme. E. COMMISSION. Brussels.

4. Task 3: Assessment and design of a "climate smart agriculture" label

4.1 Introduction

Covering half of the EU-28's surface, the EU agricultural sector is currently responsible for 10% of EU wide anthropogenic GHG emissions[85]. Between 1990 and 2012, agricultural emissions decreased by over 20%, mainly through reductions of CH_4 (ruminants' digestive processes) and N_2O (use of fertilizer) emissions. In terms of non-CO2 emissions, the agricultural sector currently accounts for 47.5% and 72.2% of total EU CH_4 and N_2O emissions respectively. In 2013 agricultural emissions, mainly CH_4, increased slightly after which they have stabilized during the last years. Land use and forestry activities (the so called LULUCF sector, acronym for Land Use, Land Use Change and Forestry) sequester 6.8% of EU anthropogenic greenhouse gas emissions.

Climate smart agriculture (CSA) aims to combine the objectives of agricultural systems to support food security with responding to the need for climate adaptation and utilizing the potential for mitigation[86]. Climate smart agriculture can be implemented through a broad portfolio of measures that can imply a change of farm management or a change of land use. While over 80% of EU farms has one or several CSA practice in place as demonstrated in Task 2, these is a significant potential for increased adoption of CSA measures in the EU agricultural sector. The availability of certification schemes has been demonstrated to increase farmers environmental engagement (Papadopoulos et al., 2015). Since the adoption of CSA practices might (initially) imply higher costs for farmers, a certification scheme labelling low-carbon food products allowing for price differentiation might guide sustainable consumer choices and thereby incentivize farmers to convert to CSA practices.

This task assesses policy options for the design of a CSA label. Based on a review of 60 existing carbon labels on both food and non-food products and services, the existing carbon labelling landscape was mapped. Existing carbon label designs were categorized according to 12 labelling characteristics, which were reorganised into nine well-defined characteristics that could be grouped into three categories which contain the building blocks of each certification scheme: Design & Scope, Governance, and Information to end users[87].

The mapping exercise was presented to environmental labelling and LCA experts by means of semi-structured interviews (see list of interviewees in Annex 12). Expert views were triangulated with findings from desk research on willingness to pay, existing EU certification initiatives and scientific literature, supporting the assessment of a selection of six policy options for the design of a voluntary CSA scheme.

In order to explore potential synergies with existing EU initiatives and investigate which type of certification requirements - is best suited to incentivize CSA, the costs and benefits associated with the following six policy options for the development of a "climate smart agriculture" label were assessed, including their certification requirements, scope, monitoring methodologies and communication to consumers:

[85] European Environmental Agency (EEA), 2018: Annual European Union greenhouse gas inventory 1990 – 2016. EEA Report No 5/2018.

[86] Food and Agriculture Organization of the United Nations (FAO), 2010: Climate Smart Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation.

[87] The policy options are not limited to labels targeting individual consumers only. Therefore, the term 'end user' is used when indicating all types of buyers along the supply chain, including individual consumers. The term 'consumer', is used for the individual consumer buying a product at a local shop or supermarket.

- Integration of CSA criteria into an **existing EU labelling scheme**
    1. Integrating **input** and **output**-based CSA criteria into the **EU Ecolabel** (i.e. an EU Ecolabel for farming products)
    2. Integrating **input**-based CSA criteria into the **EU Organic label** (i.e. update the organic standards with more climate-oriented requirements)
    3. Integrating **input**-based CSA criteria in the **EU Organic label** as **add-on** (i.e. an optional additional certification scheme for organic farmers who aim to adopt CSA practices)
- Developing a **new** CSA label
    4. Developing a **new input**-based CSA labelling scheme (i.e. a ”climate only” low-carbon farming certification scheme)
    5. Developing a **new output**-based CSA labelling scheme (i.e. a Product Carbon Footprint for farmed products)
    6. Developing a **new hybrid** CSA labelling scheme (i.e. a labelling scheme setting **input-based** criteria and measuring **output**)

By means of these options the study investigates which type of certification requirements - is best suited to incentivize CSA, **input-based criteria** which explicitly prescribe the measures manufacturers have to adopt or ban in order to be certified or **output-based criterion** which impose measurable thresholds on environmental outputs such as GHG emissions, without specifying how these should be respected.

4.2 Terminology

Based on the review of existing labelling practices as well as existing classifications of environmental certification schemes we define key concepts used in this report as follows:

- **Carbon or climate label**: any certification scheme accounting for GHG emissions related indicators, be it benchmarked emission reductions, carbon footprinting, carbon offsets, low-carbon practices, …
- **Carbon footprint (CF)**: the total amount of carbon dioxide equivalence (CO2e) associated with a product, service or organization determined through life-cycle assessment. This includes both carbon sources and sinks.
- **Product Carbon Footprint (PCF)**: the carbon footprint of a product or service rather than an organization
- **Product environmental footprint (PEF)**: measurement of life-cycle impacts related to a product across several environmental dimensions
- **“Climate smart agriculture” (CSA) label**: labelling scheme which certifies CSA related indicators, ranging from low-carbon agricultural practices (e.g. reduced or no tillage, crop rotation, the use of cover and catch crops, maintenance of permanent grassland) to benchmarked emission reductions and carbon footprinting, …
- **Life-cycle assessment (LCA)**: assessment of a product’s environmental and/or climate impacts, related to all phases of its production process, from the production of raw materials, processing, manufacturing, transportation, retail, consumer use, and disposal.
- **Product certification requirements**: requirements specifying which criteria products or production processes have to fulfil in order to be certified

- **Input or best-practice based criterion**: criterion that explicitly prescribes the measures manufacturers have to adopt or ban in order to be certified.
- **Output- or result- based criterion:** criterion that explicitly set thresholds on measurable environmental outputs such as GHG emissions, without specifying how these limits should be respected.

4.3 Literature review of studies on consumers' willingness to pay (WTP) for carbon labelled food products

Investigating consumers' understanding of carbon labels and their related willingness to pay a price premium (i.e. the additional retail cost) for carbon labelled food products is critical when assessing policy options for the design of a climate smart agriculture-label. Measuring the effects of a carbon label on consumers' WTP is relevant not only to understand consumers' purchasing behavior for carbon labelled products, but also to inform producers and farmers on the related marketability of certified food products. This is key as reporting obligations to qualify for certification may be resource intensive and production costs or investments may increase, depending on a given scheme's certification requirements.

4.3.1 Methodology

In what follows we provide an overview of the state-of-the-art of studies on consumers' willingness to pay (WTP) for sustainability action in the food sector, with a special focus on consumers' WTP for a premium on carbon-labelled food products. To this end, we conduct a systematic review of academic journals obtained from an online database of scientific articles (ScienceDirect[88]).

Our explicit and transparent search strategy design adopts a funnel approach, by which explicit criteria for inclusion ('keywords') are progressively added to the research. The timeframe within which the literature was selected is 20 years (1998-2018). Table 17 presents the sequential order of the use of keywords and the related research results. It is worth noting that adding the keyword 'premium' considerably narrows down the scope of the search, leading to a significantly lower number of articles found. This indicates that research on consumers' WTP for sustainability action in the food sector is rather limited.

Table 17 - Research results by keywords (ScienceDirect)

Keywords	Results
'food' AND 'label'	258,847
'food' AND 'label' AND 'environmental'	98,675
'food' AND 'label' AND 'environmental' AND 'consumers' AND "willingness to pay"	2,276
'food' AND 'label' AND 'environmental' AND 'consumers' AND "willingness to pay" AND 'premium'	1,162
'food' AND 'label' AND 'environmental' AND 'consumers' AND "willingness to pay" AND 'premium' AND 'carbon'	376
'food', 'environmental', 'label', 'consumers', 'willingness to pay', 'premium', 'carbon footprint'	142

Source: Ramboll Management Consulting

[88] Science Direct, 2018: Explore scientific, technical, and medical research on ScienceDirect. Available at: http://www.sciencedirect.com/. Accessed on 05 Nov. 2018

The search results sample of 376 academic articles on WTP for carbon labels are manually screened to assess the reliability and validity of the studies. By means of an evaluation matrix the purpose, geographical scope, methodology, main findings and limitations of the studies are mapped.

From the sample of 376 articles, 18 peer-reviewed papers are selected based on their relevance to the study (see full list in section C of the references chapter). This selection is done by narrowing down the focus of the research to consumers' willingness to pay a premium for carbon labels on food products exclusively. Very few studies thus investigate WTP for a specific carbon label on food products. The evaluation and synthesis of the findings of this final pool of articles are presented in Table 18.

When limiting the geographical scope of our research to European countries only, the sample accounts for 11 articles. The remaining articles focused on Japan[89], Chile[90] and the United States[91].

Studies on WTP are limited to specific products and population samples. Since no study addresses the WTP of a representative sample of European consumers for a wide range of agricultural products, any result of a literature review needs to be interpreted with caution and cannot be extrapolated. We therefore present the results of the studies in their context and format.

4.3.2 Findings on willingness to pay

The food products considered while carrying out the studies had to be consumed and known widely[92]. As such, three studies focus on the WTP for carbon-labelled milk[93]. Other products assessed are fruit (e.g. oranges), meat, wine, chocolate, and tomato.

Most studies[94] reviewed or experimented with certification schemes that specified the carbon footprint of food products. Other labels certified verified emission reductions (Feucht & Zander, 2018) or the producer-retailer distance travelled (Caputo *et al.*, 2013). Some studies also included a comparative analysis of carbon labelling schemes with organic and animal welfare labelling[95]. Six studies (out of 18 articles reviewed) quantified consumers' WTP for carbon-labelled food products.

The findings of these six studies are presented in Table 18 below.

[89] Aoki, K., Akai, K., 2013: Do Consumers Select Food Products Based on Carbon Dioxide Emissions? Springer Berlin Heidelberg, pp. 345–352.

[90] Echeverría, et al. 2014: Willingness to pay for carbon footprint on foods", British Food Journal, Vol. 116 Issue: 2,

[91] Caputo et al. 2014: Consumers' valuation of sustainability labels on meat. Food Policy 49, 137–150.

[92] Echeverría, et al. 2014: Willingness to pay for carbon footprint on foods", British Food Journal, Vol. 116 Issue: 2,

[93] In Echeverría *et al.*, 2014; Feucht & Zander, 2018; and Lombardi *et al.*, 2017.

[94] Studies which explicitly described the characteristics of the carbon label

[95] Koistinen *et al* 2013: The impact of fat content, production methods and carbon footprint information on consumer preferences for minced meat. Food Quality and Preference 29, 126–136 and Van Loo *et al.*, 2014: Consumers' valuation of sustainability labels on meat. Food Policy 49, 137–150

Table 18 - Findings of studies quantifying WTP for carbon labels on food products

Study	Food product(s)	Findings
Aoki, K., Akai, K. (2013)	Oranges	The marginal WTP estimate for the reduction of 1g of CO_2 emissions per orange was 0.642 JPY (**0.005 EUR**) in the high environmental consciousness group and 0.286 JPY (**0.0022 EUR**) in low environmental consciousness group, respectively.
Echeverría, Hugo Moreira, Sepúlveda, & Wittwer (2014)	Fluid milk and bread	Consumers are willing to pay 29% for fluid milk and 10% for bread, over their average prices - $550 CLP (**0.69 EUR**) per liter of fluid milk and $845 CLP (**1.06 EUR**) per kilogram of bread.
Feucht, Y., & Zander, K. (2018)	Milk	Consumers were willing to pay a price premium for climate-friendly labeled food in all study countries. Price premiums for the CO²_A label[96] compared to the average market price for milk ranged between 7% (**0.14 EUR/l**) in Norway and 20% (**0.24 EUR/l**) in Italy. The German participants were willing to pay a price premium of 15% (**0.13 EUR/l**) for the PCF label and a premium of 12% (**0.10 EUR/l**) for organic production compared to the average market price. It is noteworthy that the stated WTP for organic milk was lower than the average price premium for 1 l of organic milk at that time in all study countries with the exception of Italy.
Lombardi, G.V., Berni, R., Rocchi, B. (2017)	Milk	The average price premium paid for products with carbon labelling (CO_2) is **0.55 EUR/l** higher than the basic price of the experiment design (**0.84 EUR/l**);
Mostafa, M.M. (2016)	Several	Consumers in Egypt are willing to pay a price premium of approximately 75-90 Egyptian pounds (EP) for carbon-labelled products **(3.61 - 4.34 EUR)**.
Van Loo, E. J., Caputo, V., Nayga Jr, R. M., & Verbeke, W. (2014).	Meat	Belgian consumers were willing to pay a price premium of **up to 24%** for carbon-labelled chicken breast.

Source: Ramboll Management Consulting

While single studies show isolated effects for certain types of products, population samples and label designs, the majority of studies found that consumers are willing to pay a price premium for carbon-labelled products.

Overall, the studies show that the premium consumers are willing to pay varies according to the type of food product. Secondly, willingness to pay varies according to the population sample, due to differences in local, national and regional cultural preferences, socio-economic variables as gender, age, educational level, and income, and general attitudes towards climate and environmental issues. Nevertheless, studies show a general positive trend in consumers' willingness to pay a premium for carbon labelled food products (7%-65%, depending on type of food products).

In addition to the population sample and type of product certified, studies point to **consumer trust** as an essential factor influencing willingness to pay. The growing amount of (food) labels, certifying products' impacts regarding environmental and social issues in combination with consumers' relatively limited knowledge about the climate or environmental impact of food, leads to consumer confusion. As Feucht and Zander note, "participants had difficulties separating climate change from other environmental and

[96] The study included two sample of climate-friendly labels in the study, CO2_A and CO2_B, differing in the layout and colours, but including the same information.

ethical topics. They tended to subsume climate change and related issues under an umbrella of environmental and ethical issues. In line with the vague knowledge about the impact of food production and consumption on climate change, people often lacked a concrete idea what climate-friendly food means. As a result, lack of knowledge about climate-friendly food was identified as an important barrier for purchasing (more) climate-friendly food"[97]. Hartikainen stated that there is substantial misunderstanding of the meaning of for instance 'product carbon footprint', and that "only 7% of the respondents linked 'product carbon footprint' spontaneously to greenhouse gas emissions associated with the product and an additional 5% of the respondents linked it to climate change"[98].

In order to deal with consumer confusion, studies point not only to the importance of improved public awareness of the climate impact of food, but also to the role of effective policies supporting genuinely climate-friendly food production, in combination with mechanisms to guarantee the veracity of climate claims.

Overall, it can be concluded that there is a **willingness among certain consumers to pay** a higher retail price for carbon labelled food products. This willingness to pay can be increased (i.e. WTP for a higher price premium) and broadened (i.e. WTP among more consumers) when consumer trust in food ecolabelling is improved. This can be done by means of **policies supporting climate-friendly production**, in combination with **improved public information on the climate impact of food** on the on hand and **guaranteeing the trustworthiness of climate claims** on other hand.

4.4 Review of carbon labelling schemes

4.4.1 Methodology

The number of labelling schemes certifying GHG emissions related indicators has increased significantly during the last decade. In order to inform the assessment of policy options for the design of a CSA-label, this section presents a review of 60 existing carbon labelling schemes certifying GHG emission related indicators. These ranged from benchmarked emission reductions, emission monitoring, quantified carbon footprinting, carbon offsets, low-carbon practices etc.

The project's focus on agriculture was broadened to include schemes certifying any product's or organisation's climate impact. This allowed learning from a broad spectrum of certification options

Certification of GHG emission related indicators was the main selection criterion. However, many labels certify broader sustainability impacts ranging from environmental to social considerations, which were mapped as well.

Based on those selection criteria, 60 carbon labels were identified. The main source of information was the Ecolabel Index[99] for which we purchased a subscription giving access to the full ecolabel database, i.e. about 463 ecolabels. By using the search function and looking for 'carbon' or 'carbon offsets', the majority of listed labels were identified. By means of desk research additional labels discussed by previous research were identified. Furthermore, carbon labels developed in the context of EU LIFE projects (see section 4.5.5) and those assessed by scientific literature were also added to the list.

[97] Feucht, Y., Zander, K., 2018: Consumers' preferences for carbon labels and the underlying reasoning. A mixed methods approach in 6 European countries. Journal of Cleaner Production 178

98 Hartikainen, et all. 2014: Finnish consumer perceptions of carbon footprints and carbon labelling of food products. Journal of Cleaner Production p. 292

[99] Ecolabelindex.com, 2018: Who's deciding what's green? Available at: http://www.ecolabelindex.com/. Accessed on 19 Oct. 2018.

As a next step, the certification schemes were mapped and reviewed systematically on 12 characteristics. Eight characteristics were considered to be relevant for the development of policy options for the potential design of a CSA label. The matrix mapping all 60 selected labels can be consulted in Annex 8.

Table 19 - Overview of mapped characteristics of carbon labels

General characteristics	Essential characteristics
1. **Geographical scope**	5. Labelling and certification organisation
2. **Year established**	6. Value chain covered
3. **Food products covered**	7. Label features (certification logo or other)
4. **Uptake**	8. Main cause for certification
	9. GHG emission information obligation
	10. Certification requirements
	11. Standard setting norm(s)
	12. Governance mode

Source: Ramboll Management Consulting

In our list of labels, the first label certifying carbon reductions was the German Blue Angel label that was established in 1978. Most labels have been developed between 2006 and 2010 when more than four new labelling schemes were launched every year. In 2007 the creation of carbon labels saw its peak when nine new labels were launched.

Nearly half of the labels (27) certify products and/or organisations all over the world. The other half focusses on a specific country or region.

Most labels (22) are administered by a **private labelling organisation**. Another 16 are managed by **non-profit organisations**, and 9 by **governmental organisations**. Four schemes have been developed by **companies** labelling their own products.

While most labels simply indicate that **emissions have been quantified** (32 labels), and/or **emissions have been reduced** (31 labels), 11 labels indicate levels of performance by means of a **tiered system**. This is for instance displayed by using a colour code or assigning products to different categories such as silver, gold and platinum. Overall, 12 carbon labels, both tiered and non-tiered, measure the product **carbon footprint**. Furthermore, 26 labels certify emission reductions by certifying or providing the option of **emission offsetting**. Another five labels only grant certification if the product's **carbon footprint is lower than a product benchmark** in its respective product group.

A large majority of labels rely on **life cycle assessment** (LCA) methodologies to assess a product or organisation's carbon and/environmental footprint. The level of thoroughness of the LCA method varies. Certain labels focus on **specific stages of a product's life cycle**, such as the emissions related to agricultural inputs.

The methods for conducting such an analysis are often standardised by the International Organisation for Standardization (ISO), which regularly publishes updated ISO norms. While most carbon labels (33) rely on the **ISO norms**, many labels are verified according to a combination of methodological standards. Other emission measurement guidance is provided by the **Publicly Available Specification (PAS)** developed by the British Standards Institution (BSI) (16 labels), the **Greenhouse Gas Protocol** developed by the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) (10 labels), **the International Reference Life Cycle Data System (ILCD)** by the European Commission (1 label), the **IPCC Guidelines for National Greenhouse Gas Inventories** (3 labels) and the **BPX 30-323 standard** developed by the French Environment and Energy Agency (ADEME) (1 label). A total of 17 listed carbon labels **do not rely on any standardisation norm**.

As 37 labels have products and organisations certified by an **external verifier**, the labels also rely on norms for third-party auditors, such as the **Environmental Management System (EMS) Auditor** (1 label), **ISEAL Code of Good Practice for Setting Social and Environmental Standards** developed by the International Social and Environmental Accreditation and Labelling Alliance (ISEAL Alliance) (3 labels), **EPA Requirements for EPP Product Certifiers** by the US Environmental Protection Agency (EPA) (1 label) and several **ISO norms**. Another 15 labels are verified **by the organisation issuing the certificate** and three rely on **self-verification** by the producer or organisation that aims to be certified.

A large majority of labels certify any type of product or organisation. We have identified seven carbon labels that exclusively certify agricultural products and two labels that certify agricultural products and some additional type of products (flowers and paper products respectively).

Table 20 lists 17 labels active in the EU which certify carbon related indicators for agricultural products. One of these labels comes closest to a potential “climate smart agriculture” label, which is assessed in more detail in section 4.4.2).

Table 20 - Active carbon related labels for agricultural products in the EU

Name	Labelling organisation	Geographical scope	Certification scope	Agricultural products covered	Market uptake
AB Agri GHG Modelling	AB Agri for supermarket Sainsbury	UK	GHG emission indicators	Dairy, beef, sheep, pig and poultry, eggs, wheat etc.	>900 farmers
Bonsucro Production Standard	Bonsucro	Global	Social and environmental performance; GHG emission indicators	Sugar cane	207 companies
Carbon Footprint Assessment	Soil & More International	Global	GHG emission reductions and offsets	Bananas	Unknown
Carbon Footprint Label	Raisio Group	Finland	GHG emission indicators	Food products	Unknown
Carbon Reduction label	Carbon Trust	UK/ Global	GHG emission indicators and water use	Food products and others	>25 000 products
Climatop	My climate	Global	GHG emission indicators; environmental and social standards	Food products and others	11 companies; 65 products
HAproWINE PCR	HAproWINE LIFE project	Spain	GHG emission indicators; environmental performance (water use, eutrophication potential, hazardous waste)	Wine	Unknown
Indice Carbone	Casino warehouse	France	GHG emission indicators	Warehouse products	11 700 products
Klimatcertifierad	Svensk Sigill	Sweden	GHG emission indicators; social and environmental performance (animal welfare, soil and nutrient management, pesticide use, nutrient leaching, biodiversity and water use)	Food products and flowers	61 products in 2012
Label CO2 Bilan CO2	E. Leclerc	France and Switzeland	GHG emission footprint	Food products	20 000 products
Leaf marque	LEAF Marque Ltd	Europe	GHG emission indicators, environmental protection (soil management, water use and water quality, energy efficiency and energy use, waste management, livestock management and biodiversity)	Farmed products	>1000 businesses
Nature & More	Soil & More	Global	Climate, water, soil, health, biodiversity, livelihood aspects	Fruits and vegetables	Unknown
On the way to PlanetProof	Stichting Milieukeur	Global, NL	GHG emission reductions	Vegetable and dairy products	379 companies
Per il clima	Legambiente Turismo	Italy	GHG emission	Food products and others	15 products

Name	Labelling organisation	Geographical scope	Certification scope	Agricultural products covered	Market uptake
Spanish Registry of Carbon Footprint, Offsetting and CO2 Removal	Spanish Ministry of Agriculture, Food and Environment	Spain	GHG emissions reduction commitment and offsets	Food products and others	Unknown
Stop Climate Change	AGRA-TEG GmbH	Global	Social and environmental protection; GHG emission reduction and offsets	Agricultural products	Approx. 50 products and companies
UTZ Certified	UTZ Certified	Global	Social and environmental protection; crop diversification;	Coffee, tea, cacao and hazelnut	>15 000 products

4.4.2 Klimatcertifierad: A low-carbon farming certification scheme

The Swedish climate certification initiative Klimatcertifierad, or Climate Certified, was initiated in 2007. Krav, the largest Swedish organisation for the development of organic standards and Sigill Kvalitetssystem AB (Swedish Seal), a farmers-owned for-profit labelling organisation managing the quality label of the Federation of Swedish Farmers developed the initial certification requirements in collaboration with several major Swedish food companies (Milko, Lantmännen, the Federation of Swedish Farmers, Scan and Skånemejerier). The label certifies food products - ranging from meat, fish, milk, greenhouse vegetables to food crops - and flowers. Currently, Swedish Seal manages the ongoing development of the certification requirements[100].

Integration into existing certification schemes

The scheme functions as an add-on that can be integrated in existing labels. Climate certification can thus only by attained in combination with another certification scheme. As of 2010 Krav incorporated the requirements into their organic certification scheme. The organic label does not specifically communicate this to consumers.

Swedish Seal on the other hand introduced a voluntary, additional certification level, with a logo to communicate certification to consumers. The scheme functions as the third stage in a process of increasingly strict certification requirements related to sustainable agricultural production. First level certified products comply with basic food safety and animal welfare levels specified in Swedish legislation. The second level sets stricter animal welfare and food safety requirements, as well as environmental protection criteria, ranging from safe and limited use of pesticides, minimized nutrient leaching into water bodies, biodiversity protection, and sustainable use of water.

Climate Certified products are thus assessed according to multiple sustainability and quality criteria. The project's information brochure[101] argues that "Climate is only one component of sustainable development" and that "focusing on the climate question alone can lead to sub-optimal solutions."

Climate certification requirements and means of verification

Klimatcertifierad is a low-carbon farming certification scheme. Neither the specific carbon footprint of a product nor the farm is not explicitly quantified. Instead, the producer has to fulfil certain criteria which require the adoption of specific practices. These are specified in product specific rulebooks and include for instance demonstrated energy savings, 100% renewable electricity supply, crop rotation, and use of climate-friendly animal feed.

The development of certification requirements relies on LCA data. These are used to identify the most GHG-intensive stages of a given production process, as well as the practices with the highest GHG emission reduction potential. This scientific scan determines the reduction potential of a given production process, which varies significantly per product category. For instance, emissions associated with greenhouse vegetables can be reduced by around 80% due to the large reduction potential associated with the

[100] Expert Interview Sigill Kvalitetssystem AB – 8 October 2018

[101] Klimatmarkningen, 2010: Klimatcertifiering av livsmedel och blommor, Available at: http://www.klimatmarkningen.se/wp-content/.../2010-10-19-klimatfolder-engelsk-print. Accessed on 2 Nov. 2018.

transition to renewable energy use. The emission reduction of meat production is limited to around 5-10%. On average across all certified product categories, an emission reduction of 25% is expected.

While emissions are not measured for each farm of product specifically, the LCA-based criteria should guarantee reduced climate impact within a specific uncertainty range.

Processed foods composed of different ingredients are assessed according to the certification of the primary raw material (i.e. the main ingredient). For the processed product to be Climate Certified, 90% of this ingredient needs to be Climate Certified.

Compliance is verified by external auditors, who check the implementation of the rulebook by means of annual on-site visits. Farmers pay an annual license fee of around €300-€1,000[102] to Swedish Seal and a biannual audit-fee of €300-€800[103] every second year to the external certification body, depending on the size of the business.

4.4.3 Mapping exercise

Annex 9: Carbon labelling mapping exercise presents the final mapping exercise that has been deducted from the analysis of carbon labels, the review of EU initiatives, expert interviews, as well as additional desk research. The 12 label characteristics presented in section 4.4 were reorganised into nine well-defined characteristics. These could be grouped into three categories which contain the building blocks of each certification scheme: Design & Scope, Governance, and Information to end users. For each of the nine characteristics the main alternatives found among the 60 labels were listed.

[102] 3,000 – 11,000 SEK

[103] 3,000 –8,000 SEK

4.5 Overview of EU initiatives and LIFE projects

The EU has so far developed several labels related to environmental topics and has implemented initiatives related to environmental labelling on different levels. This section will outline these European initiatives and LIFE projects in order to learn from these actions, benefit from potential synergies and avoid unnecessary overlaps.

4.5.1 EU Ecolabelling

The EU Ecolabel or EU Flower is a voluntary certification scheme for products and services established in 1991, and currently regulated under Regulation (EC) No 66/2010. The scheme is managed by the European Commission's Directorate-General for the Environment (DG Environment), supported by the European Union Ecolabelling Board (EUEB). The EUEB groups Competent Bodies of the European Economic Area and the label's stakeholder Consultation Forum. The scheme is part of the EU Action Plan on Sustainable Consumption and Production. The EU Ecolabel is listed among the carbon labels presented in It certifies emission reductions, among other environmental impacts such as recyclability, energy use, water efficiency and product longevity.

Certified products and services comply with a set of benchmarking criteria which indicate the product is among the top 10-20% of environmentally best performing products within its respective product group. Currently, criteria were developed for 26 product groups certifying 72,227 products and services[104].

With regards to overall effectiveness the 2017 Commission evaluation of the EU Ecolabel[105] concluded that while the Ecolabel sets criteria that could lead to environmental benefits, more attention should be given to potential producer uptake when developing the criteria, as the actual adoption of criteria by producers is essential to realize environmental benefits. For some product categories producer uptake is particularly low or even zero, which the evaluation attributes to industry dissatisfaction with the criteria which are regarded as too stringent to comply with. This points to an essential "effectiveness" trade-off many ecolabels face between the label's environmental ambition and the feasibility for producers to comply with these criteria.

In addition, the evaluation identifies low consumer awareness and thus low incentives for manufacturers to apply for certification as a key factor impacting effectiveness.

Regarding efficiency, the criteria development process is regarded as complex, which results in high compliance costs for manufacturers. While this is already addressed by the latest revision of the legislation, the evaluation recommends simplifying requirements further by setting simpler and fewer criteria, focussing on key environmental impacts. This reveals a second trade-off – the "efficiency" trade-off between a detailed monitoring of environmental improvements and the administrative burden to comply with such criteria.

[104] Ec.europa.eu., 2018: *Facts and Figures - Ecolabel - EUROPA*. Available at: http://ec.europa.eu/environment/ecolabel/facts-and-figures.html. Accessed on 27 Oct. 2018

[105] Barberio, M. et al., 2017: Evaluation of the Implementation of the EU Ecolabel Regulation. Available at: https://publications.europa.eu/en/publication-detail/-/publication/a779f801-5498-11e7-a5ca-01aa75ed71a1. Accessed on 27 Oct. 2018

Criteria development and certification of GHG emission reductions

The EU Ecolabel benchmarking criteria determine whether a product can be certified as being among the 10-20% best performing products. By means of LCA methodologies the European Commission Joint Research Centre (JRC) identifies the most significant environmental impacts of a product's life-cycle. For these life-cycle stages the JRC proposes product group specific criteria, which are further refined through a multi-stakeholder process to determine measures with highest GHG emission reduction potential.

Manufactures wishing to have their products certified have to provide evidence demonstrating they comply with the criteria. For each product group user manuals are available which explain what data needs to be gathered.

In setting criteria for product categories, the EU Ecolabel Regulation explicitly mentions the need to consider the impact on climate change. GHG emissions are thus addressed in case they cause significant environmental harm and if there is scope for reduction. For some product groups having significant climate impact, such as paper products or rinse-off cosmetic products, criteria are developed to award the Ecolabel to those products emitting least GHG emissions compared to their product group benchmark. For other product groups such as bed mattresses[106] and indoor and outdoor paints and varnishes[107] the Ecolabel does not certify emission reductions, either because the climate impact of the product group is limited or because there is limited scope for improvement in this area.

Every four years on average, the criteria are revised to reflect technical innovation, and improved methodologies such as updated emission factors. This ensures that the label continues to certify only the 10-20% best performing products.

Further details of the scheme's characteristics can be found in Table 21 below.

Table 21 - EU Ecolabel characteristics

Label Characteristic	EU organic Label
Administering organisation	Governmental organisation: European Commission DG ENVI & Member States
Verification mode	Third-party verification
Governance structure	• The European Commission manages the scheme at EU level • The European Union Ecolabelling Board (EUEB) is responsible for developing, revising, publishing and promoting criteria for product groups, in collaboration with the Commission. The EUEB is made up of Competent Bodies responsible for implementing the EU Ecolabel scheme at national level and relevant stakeholders[108] • Competent Bodies evaluate manufacturers and service providers' applications, award the Ecolabel certification to products meeting their product group criteria and supervise the verification process
Standard-setting norm(s) for verification	ISO 14020

[106] Europa.eu, n.d.: The EU Ecolabel for Bed Mattresses "The official European label for Greener Products". Available at: http://ec.europa.eu/environment/ecolabel/documents/bed_mattresses.pdf. Accessed on 17 Oct. 2018

[107] Europa.eu, n.d.: The EU Ecolabel for Indoor and outdoor paints and varnishes "The official European label for Greener Products" Available at: http://ec.europa.eu/environment/ecolabel/documents/paints.pdf Accessed on 17 Oct. 2018

[108] The European Environmental Bureau (EEB), the European Consumer Organisation (BEUC), the European Confederation of Associations of Small- and Medium-Sized Enterprises (CEA-PME), Business Europe, EUROCOOP, the European Association of Craft, Small- & Medium-Sized Enterprises (EUAPME) and EUROCOMMERCE.

Label Characteristic	EU organic Label
Standard-setting norm(s) for third party verification bodies	• ISO 17011 • IEC Guide 65
Value chain covered	LCA-based criteria for life-cycle stages with highest environmental impact
Certification requirements	Environmental performance compared to product benchmark (top 10-20% of environmental preferable products within a certain product group)
Certification scope	• GHG emissions • Environmental protection • Waste minimization • Recyclability • Energy use • Water pollution prevention • Water management and reduction • Product longevity • Renewable raw material use
Reporting obligations	• Producers that wish to have their products certified must be registered on-line and provide the necessary evidence. • User manuals supporting this process are provided for each product group. • Evidence is submitted to the appropriate Competent Body which assesses the applications and determines whether the EU Ecolabel can be awarded.
Label features	Certification logo with EU Ecolabel website where additional information can be found
Agricultural products covered	None
Uptake	72,227 products and services within 26 product categories since September 2018

Source: European Commission

Certification of food products

The label does not certify agricultural products. Following a feasibility study[109] assessing the possibility of integrating food and feed products into the EU Ecolabel, the European Union Ecolabelling Board (EUEB) issued the opinion not to pursue this option[110]. As part of its motivation it referred to the expectation of consumers to include ethical and social standards into an ecolabel for food products, the consumer confusion in relation to the number of environmental labels for food products and complexity and costs of the development of such label.

These issues are further explored in the assessment of policy options presented in section 4.6.

[109] Sengstschmid et al. 2011: Feasibility study: EU Ecolabel for food and feed products. Oakdene Hollins Research & Consulting.

[110] Europa.eu, n.d.: Opinion of the European Union Ecolabelling Board: On the development of EU Ecolabel for food and feed products. Available at: http://ec.europa.eu/environment/ecolabel/documents/EUEB_position_on_food_final.pdf. Accessed on 20 Oct. 2018.

4.5.2 EU Organic Labelling

A second label administered by the European Commission is the **EU Organic Label**. The label was set up in 1991 with the aim to protect consumers and organic farmers against false and misleading organic claims by setting EU-wide minimum standards for organic farming. The label's requirements are set out in Regulation 834/2007 and managed by Directorate-General for Agriculture and Rural Development (DG Agriculture).

The organic label certifies products of which at least 95% of ingredients meet the EU organic standards. In setting the organic standards, the Commission is assisted by a regulatory Committee on organic production, composed of the representatives of all Member State Competent Bodies, as well as an expert group. This Committee approves implementing regulations proposed by the Commission. Table 22 below summarises the characteristics of the EU Organic Label.

Table 22 - Overview of EU Organic Label characteristics

Label Characteristic	EU organic Label
Administering organisation	Governmental organisation: European Commission DG AGRI & Member States
Verification mode	Annual third-party verification
Governance structure	• The European Commission manages the scheme at EU level • The Competent Bodies are independent and impartial organisations designated by the Member States who are responsible for the verification process. They may delegate control tasks to public or private control bodies. They may adopt standards that are stricter than the European standard • The Expert group for technical advice on organic production provides advice to the Commission on evaluating and systematic updating of the standards • The Committee on Organic Production, comprising of representatives of all competent authorities approves the implementing regulations proposed by the Commission
Standard-setting norm(s) for verification	None
Standard-setting norm(s) for third party verification bodies	• ISO/IEC 17065 • ISO Guide 65 for imported products
Value chain covered	Agricultural production
Certification requirements	Organic standards laid down in Council Regulation (EC) No 834/2007 and Commission Regulation (EC) No 889/2008
Certification scope	• Environmental protection • Biodiversity protection • Preservation of natural resources • High animal welfare standards • Not more than 0.9% GMO content • Restrictions on pesticides, fertilizers and antibiotics • Limit to food additives • Local farm production inputs • Short supply chain • Crop rotation
Reporting obligations	National competent authorities responsible for controlling the activities of organic operators specify what kind of documentary evidence is required for proving that the products meet the organic criteria.
Label features	Certification logo and coded indication of the place where the agricultural raw materials of which the product is composed have been farmed
Agricultural products covered	All food products
Number of farms and operators meeting requirements	• 11.1 million hectares cultivated as organic in 2015 • 186,000 farms in 2018 • 306,500 operators in 2015

Source: Ramboll Management Consulting

The impact assessment laying the ground for the revision of the Organic Regulation found that the current legislation was found inapt to support the sustainable development of the fast-growing organic sector[111]. It suggests that the legislation is unclear and contains too many exceptions, does not create sufficient synergies with EU policies and does not address full life cycle impacts of organic production. Finally, overall complexity and administrative requirements are deemed too burdensome to foster the development of an

[111] European Commission, 2014: Executive summary of the impact assessment accompanying the document Proposal for regulation on organic production and labelling of organic products. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014SC0066 .

EU organic market especially for small farms, who are also rebutted by high costs of certification.

The 2013 Evaluation of the EU legislation on organic farming[112] similarly points to some lack of detail and clarity on certain rules, as well as different Member States' implementation and enforcement of some rules. The evaluation also highlights that while "the scope of the Regulation is mostly adequate to meet the current needs of the organic farming supply and distribution chain… it is not fully adequate to meet the needs of consumers of organic products"[113]. In that regard, the evaluation indicates that there is confusion concerning the certification and labelling of non-food agricultural raw materials; the fact that cosmetics and textiles are not covered by the Regulation may not be clear to consumers when these are labelled and certified by other non-recognised organic standards.

Responding to some of these criticisms the revision of the legislation was adopted in 2018. The new rules will apply as of 2021[114], and will simplify production rules, enable group certification for small farms, strengthen the control system and enlarge the scope of the legislation to include more products.

Criteria development and certification of GHG emission reductions

The Organic farming regulation aims to support the sustainable development of the organic farming sector by creating a widely recognized label and setting the corresponding EU-wide minimum voluntary standards. These standards are based on the underlying principles of organic production, set by the Commission in consultation with stakeholders and experts. Organic production is seen as an integrated farm management system which aims to contribute to high levels of biodiversity, preserve natural resources, respect high animal welfare standards and produce high quality food in response to consumer demand. This definition forms the basis of the development of production rules farmers have to comply with to have their products certified as organic.

Part of the Organic farming legislation's objective is thus to deliver goods that contribute to the protection of the environment. With regards to climate change, several organic farming principles contribute directly or indirectly to climate mitigation or adaptation. For instance, restricted use of external inputs such as fertilisers reduces energy use and thus GHG emissions from fossil fuels. As pointed out by the 2013 Commission evaluation of the Organic Regulation[115], organic production rules have some positive impact on limiting air pollution, including CO2 emissions. Organically farmed soils capture more organic carbon and thus have a potential for carbon sequestration. As these soils also capture more water, they could be more resilient to extreme weather events.

Several practices listed as CSA measures in Task 1 are incorporated in organic production rules. These include for instance reduced livestock density and require multi-annual crop rotation. There are however many more CSA measures that are not part of organic production rules.

Overall, it can be said that organic farming sets the right conditions for climate action and has thus the potential to contribute to climate change mitigation and adaptation. However, climate change mitigation and adaptation are no specific objectives of the Regulation. The

[112] Sanders, J., (ed.) 2013: Evaluation of the EU legislation on organic farming. Braunschweig: Thünen Institute of Farm Economics.

113 Ibid. p.IV

114Europa.eu, n.d.: New legislation from 2021. Available at https://ec.europa.eu/info/food-farming-fisheries/farming/organic-farming/future-organics_en Accessed on 27 March 2019.

115 Sanders, J., (ed.) 2013: Evaluation of the EU legislation on organic farming. Braunschweig: Thünen Institute of Farm Economics.

overall climate impact of organic practices does not necessarily differ from conventional practices[116]. Furthermore, the greater areas of land needed for organic farming, lead to a larger carbon footprint compared to conventionally farmed production volume[117]. Another trade-off between climate objectives and organic farming are the restrictions on the use of synthetic herbicides, which prompts more intense mechanical tillage techniques leading to the release of GHG emissions. While the climate impact of herbicides is unclear, there is some evidence pointing to reduced climate impacts from no-tillage over herbicide use.[118]

In conclusion, while some organic farming practices contribute to GHG mitigation, other aspects of organic farming may lead to higher climate impacts. Therefore, it is currently not possible to claim climate benefits nor measure emission reductions for a specific organic product.

4.5.3 The Environmental Footprint Guidance

The 2008 Council conclusions on the Sustainable Consumption and Production Action Plan invited the European Commission to develop "common voluntary methodologies facilitating the future establishment of carbon audits for organisations and the calculation of the carbon footprint of products"[119].

As a first step the Commission's DG Environment studied the existing methodologies and initiatives for determining product and organisational carbon footprints. While the initiative initially focussed on carbon footprints, the study outcomes broadened the scope to include all environmental impacts of products, supported by the Council conclusions on Sustainable Materials Management and Sustainable Production and Consumption of 2010[120].

In 2013 DG Environment launched the Single Market for Green Products Initiative with the aim to develop such common life cycle methodologies for measuring environmental performance of products – the Product Environmental Footprint (PEF) – and organisations - the Organisation Environmental Footprint (OEF).

Following the development of an LCA-based methodology by the European Commission's Joint Research Centre (JRC), DG Environment carried out the **Environmental Footprint Guidance** pilot phase. In order to support the environmental assessment and labelling of products and organisations across all Member States, standards for the measuring of the environmental performance of products and organizations across all Member States were developed.

Between 2013 and 2018 relevant stakeholders of the respective sectors developed so-called Product Environmental Footprint Category Rules (PEFCRs) and Organisation Environmental Footprint Sector Rules (OEFSRs). These list most relevant impact categories, life cycle stages and production processes, along with a list of mandatory data, data quality requirements and solutions for potential data gaps.

[116] Knudsen et al., 2014: Carbon footprints of crops from organic and conventional arable crop rotations–using a life cycle assessment approach. *Journal of Cleaner Production*, *64*, pp.609-618. Available at: https://www.sciencedirect.com/science/article/pii/S0959652613004708. Accessed 27 March 2019

[117] Searchinger T., 2018: Assessing the efficiency of changes in land use for mitigating climate change. Available at: https://www.nature.com/articles/s41586-018-0757-z Accessed 27 March 2019

118Staropoli, 2016: No-till agriculture offers vast sustainability benefits. So why do many organic farmers reject it? Available at https://geneticliteracyproject.org/2016/06/02/no-till-agriculture-offers-vast-sustainability-benefits-so-why-do-organic-farmers-reject-it/. Accessed on 28 March 2019

119 Consilium.europa.eu, 2008. Available at: http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%2016914%202008%20INIT. Accessed on 13 Dec. 2018.

120 Council of The European Union, ENVIRONMENT Council meeting Brussels, 20 December 2010, Council conclusions on sustainable materials management and sustainable production and consumption: key contribution to a resource-efficient Europe.

For the pilot phase the Commission selected a diverse range of product categories for which good quality life cycle data is available. By the end of 2018, 2 OEFSRs, for retail and copper production, and 21 PEFCRs for both agricultural and non-agricultural products were available. Completed PEFCRs are valid until the end of 2020, after which the underlying data sets for LCA calculations expire.

The PEF/OEF process was initiated to restore consumer trust in ecolabels by reducing the proliferation of ecolabels, potential misleading claims and the related consumer confusion. Furthermore, it was judged that existing life cycle-based standards did not provide sufficient specificity to enable comparisons of environmental claims across products delivering the same function, which would require the same assumptions, measurements and calculations across certification schemes. By establishing a common methodology providing better information on the environmental footprint of products and organisations which can be used across Member States, companies operating in different Member States only need to conduct one environmental assessment, instead of the different assessments used in different national markets.

The first EU policy initiatives building on the environmental footprint guidance are to be expected around 2020/2021. Currently a transition phase until 2021 is being established during which potential future applications of PEF process are discussed. The transition phase provides a framework for the monitoring of the implementation of the existing PEFCRs and OEFRs, the development of new PEFCRs and OEFSRs and new methodological developments. A sub-group of the Commission's Expert Group on Sustainable Consumption and Production is envisioned as an advisory body. In addition, a Technical Advisory Board would be established to discuss methodological issues, among which would be representatives of the food sector.

Climate-related requirements for food products

The Environmental Footprint Guidance pilot phase developed PEFCRs for the following agricultural products: beer, diary, feed for food-producing animals, pasta, cat and dog food and wine. The PEFCR pilot process for olive oil is still ongoing. Several other food-related PEFCRs - coffee, red meat and marine fish - did not make it to completion.

For each PEFCR, a list of relevant impact categories is established. One of the impact categories to be modelled is climate change, measured through a product's Global Warming Potential (GWP100) in kg CO_2 equivalents. Depending on the product, reporting on GHG emissions can be done under up to three different sub-indicators – fossil, biogenic and land use and land transformation - aiming to capture all significant aspects of a product's climate change impact[121]. Furthermore, the PEF process enables manufacturers to identify the most impactful life-cycle stage for each impact category.

All food PEFCRs list climate change among the most relevant impact category to be taken into consideration when modelling for life-cycle impacts. For these food products, the most relevant life-cycle stage for impact category climate change often included the agricultural stage, as demonstrated in Table 23 below.

[121] Any sub-indicator representing more than 5% of total climate impact should be reported separately.

Table 23 - Examples of agricultural processes among most climate impactful lifecycle stage of food PEFCRs

PEFCR	Agricultural life-cycle stage
Beer	Cultivation of grain for malting
Diary	Raw milk supply
Feed for food-producing animals	Production of feed ingredients (e.g. maize)
Pasta	Ingredients supply (e.g. eggs)
Cat and dog food	Ingredients supply (e.g. beef cattle)
Wine	Grape production

Evaluation of the PEF pilot phase

The 2017 review of the pilot phase[122] concluded that stakeholders regarded the PEF process as a good opportunity to harmonise the LCA methodology at EU level. However, some expressed doubts concerning on the on hand the practicability and costs and on the other hand the robustness of the methodology proposed. While many stakeholders considered the methodology proposed to be robust, others thought that the choice of LCA was too complex and costly as an approach. While simplification for instance by reducing the number of impact criteria, can make the methodology more accessible, less costly, and the results more comparable, this would likely occur at the expense of robustness of the results.

Disagreements also emerged over the impact criteria used. For instance, the criterion for human toxicity was considered as not sufficiently mature to be introduced into the methodology, while other important criteria such as regarding biodiversity appeared missing.

Environmental NGOs doubted the communication of LCA data to inform consumers about products, however a differentiated approach could be used to communicate between businesses (B2B) or from business to consumer (B2C). Industry stakeholders were more positive about the PEF process.

Stakeholders also identified a risk of overlap between the PEF/OEF with other schemes, including the EU Ecolabel and industry standards, while also providing opportunities for synergies with these schemes. PEF/OEF can for instance be used in green public procurement in order for public authorities to make informed decisions.

The choice of criteria and parameters used is a highly technical discussion with potential economic implications as it determines whether a product can be labelled as environmentally sound. As companies are aware of this, disagreements over these methodological choices subsist and appeared in the pilot between different companies and industry experts. This is particularly an issue in the context of the multi-stakeholder process where larger companies or business associations with more resources available to participate in technical meetings risk being over-represented, compared to smaller industry stakeholders and civil society. One technical debate with direct relevance to the present study concerned the use of a European or national emission factor from the energy mix, with direct consequence on the GWP results for similar products produced in different countries.

[122] European Commission DG Environment, 2017: Review report of the Environmental Footprint Pilot phase. Available at http://ec.europa.eu/environment/eussd/smgp/pdf/2017_peer_rev_finrep.pdf

4.5.4 The EU Eco-Management and Audit Scheme (EMAS)

The European Commission's DG Environment developed the **EU Eco-Management and Audit Scheme (EMAS)**. This is an environmental management instrument that can be used by organisations to evaluate, report and improve their environmental performance and help them to meet the requirements of the European Environmental Management System Regulation[123]. EMAS is verified by third-party auditors. It is applicable to all sectors and has a global reach.

Organisations aiming to meet the EMAS requirements should assess their direct and indirect environmental impact on the basis of which initial benchmarks are set. It should detail how the management generally deals with the organisation's environmental aspects. As a next step an environmental policy and environmental programme should be defined, which respectively describe the organisation's commitment and environmental objectives and translate this policy into specific objectives and targets designating responsibilities and identifying the means to achieve the targets. The implementation of the environmental programme is followed by an internal environmental audit, which monitors the performance of the procedures and practices created to improve environmental performance. Regular periodic assessments are carried out by the organisation itself or by external experts. Following this assessment action must be undertaken to improve environmental performance. The next step involves the drafting of the environmental report or environmental statement which communicates the organisation's environmental performance to stakeholders. The Environmental Management System (EMS) is subsequently validated by an independent environmental verifier. In case this evaluation is positive, the organisation is registered on the European EMAS register. It can then publicly announce its efforts to reduce its environmental impact and can use the EMAS logo. The validated environmental report is publicly available. From this stage on the results of the environmental action plan should be continuously monitored to sustain and improve the actions taken. The registration is valid for three years after which reapplication is required.

The agricultural sector is identified as a priority sector for which the Commission developed a Sectoral Reference Document (SRD) on Best Environmental Management Practices (BEMPs)[124]. The objective of the SRD is to support organisations in the agriculture sector to focus on relevant environmental aspects, both direct and indirect, and to find information on best environmental management practices, as well as appropriate sector-specific environmental performance indicators to measure their environmental performance, and benchmarks of excellence. Several environmental aspects are also relevant from a climate perspectice. Those include e.g. soil management, tillage and grazing which influence adaptation pressures. For mitigation, those include nutrients application, tillage (relating to loss of C and N in the soil), grazing (influcencing NH3 and N2O emissions), feeding (CH4 emissions from enteric fermentation), animal housing (NH3 and CH4 emissions), manure storage (CH4, NH3 and N2O emissions), manure spreading (NH3 and N2O emissions) and grazing (NH3 and N2O emissions). The SRD lists best practices for addressing those environmental aspects.

[123] REGULATION (EC) No 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), repealing Regulation (EC) No 761/2001 and Commission Decisions 2001/681/EC and 2006/193/EC.

[124] Commission Decision (EU) 2018/813 of 14 May 2018 on the sectoral reference document on best environmental management practices, sector environmental performance indicators and benchmarks of excellence for the agriculture sector under Regulation (EC) No 1221/2009 of the European Parliament and of the Council on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)Text with EEA relevance . Available at: https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32018D0813. Accessed on 27 May 2019

4.5.5 EU Energy labelling: an example of a mandatory labelling scheme

The European Union established a mandatory framework for energy consumption labelling in 1992, in order to harmonise diverging national labelling schemes. Since 2010 manufacturers use a single label for the entire EU market.

After regulatory updates in 2010 and 2017, the **EU Energy labelling framework** currently regulates 16 types of energy appliances, ranging from lamps to ovens and refrigerators, setting out energy classes which categorise products on an A (most efficient) to G (least efficient) label scale[125]. The label is mandatory for all new products on the EU market, including second-hand imported products. Embedded in the EU's 2030 Climate and Energy Policy Framework, the rationale behind the legislation is to enable customers to choose products that consume less energy while also encouraging companies to develop and invest in energy-efficient products. These specific objectives should contribute to the EU's 2020 and 2030 energy-efficiency targets, as well as GHG emissions reduction targets.

The responsibilities for the scheme's governance are split between the European Commission and the Member States. Manufacturers are required to label their products according to the appropriate energy class, while Member States need to monitor the market and enforce the Regulation by imposing penalties on non-abiding companies. The European Commission's Directorate-General for Energy (DG ENER) is responsible for elaborating the guidelines and creating a product database to support market surveillance by Member States. The Commission can furthermore supplement the existing regulatory framework by adopting delegated acts, after consulting with the relevant stakeholders such as industry representatives, trade unions or environmental and consumer organisations, as to update requirements relating to labels for specific product groups.

Within the mandatory framework manufacturers bear the costs associated with labelling. However, an EU commissioned evaluation of the 2010 Directive[126] shows that these costs are passed on to the end-users (households and businesses) who benefit from cost savings due to reduced energy use, which considerably outweigh the upfront purchase costs. The label has thus had a positive impact on climate change mitigation as iwas estimated that mandatory energy labelling will result in energy savings of 175 million tons of oil equivalent a year, by 2020. Including the avoided GHG losses from refrigerants this amounts to a reduction of 306 Mt CO2eq.[127] For an average household, the label should result in €500 annual energy savings. Energy labelling should furthermore generate €55 billion in additional revenue for European companies.

The mandatory nature of the Directive allows for the label scale to function as an incentive for producers to manufacture better performing appliances. In case labelling were not mandatory, producers at the lower end would not apply for certification, which highlights a key difference between a mandatory and a voluntary label. Section 4.6 explores options for a voluntary labelling schemes and will thus not consider performance scales such as the so-called "traffic light" label.

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[125] Europa.eu. 2018: *Energy labels*. Available at: https://europa.eu/youreurope/business/product/energy-labels/index_en.htm. Accessed on 19 Dec. 2018.

[126] European Commission, 2015: *Review of Directive 2010/30/EU.* Available at: https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_ACT_part1_v5.pdf. Accessed on 19 Dec. 2018

[127] European Commission, 2019: Ecodesing Impact Accounting. Status report 2018. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf. Accessed on 27 March 2018

4.5.6 Relevant EU LIFE projects

One of the EU's financial instruments to support its environmental, nature conservation and climate action is the LIFE programme. Projects promoting one or several of these pillars can apply for funding.

Several LIFE projects have touched upon environmental labelling. Annex 10: Overview of LIFE projects gives an overview of the LIFE projects[128] relevant for the development of a "climate smart agriculture" label. In addition, we added several LIFE projects which explore ways in which EU agriculture can contribute to climate adaptation and mitigation. Two projects developed a carbon label and were included into the overview of carbon labels: the HaProWINE and the Foodprint labels. Four projects account for GHG emissions by means of a life-cycle analysis, four developed a software tool to support measurements relevant for obtaining ecolabels, three projects developed ecolabels without accounting for GHG emissions, one project promoted the uptake of ecolabels and one assisted companies to obtain ecolabels.

4.5.7 Lessons learnt

While the EU initiatives and LIFE projects on carbon labelling have explored essential aspects of carbon certification, none of these provides a ready-made voluntary carbon certification scheme that is applicable to the agricultural sector as a whole. The EU Ecolabel explicitly excludes agricultural products from its range of certified products. The EU Organic Label on the other hand is applicable to agricultural products but does not explicitly account for GHG emissions. Several lessons for a potential CSA label can however be drawn from the relative success of two EU administered labelling schemes, the **EU Ecolabel** and the **EU Organic label**, as well as the EU's **PEF initiative** aiming at harmonising LCA methodologies.

Below we summarise key characteristics of both EU labels and exemplify how they both aim to address what we call the effectiveness and efficiency trade-offs. We then go on to outline the distinction between input and output-based certification requirements, relevant for the development of a CSA label.

EU certification initiatives: finding a balance to ensure effectiveness and efficiency

Labelling initiatives on the one hand aim to balance **ambition** (i.e. setting environmentally stringent product criteria that can foster the label's reputation for environmental protection) and **feasibility** (i.e. setting product criteria producers can meet at reasonable compliance costs). A right balance of this "effectiveness trade-off" should ensure the label's effectiveness.

On the other hand, the EU labels aim to find a middle ground between their **credibility** (i.e. governing the label in a credible way which includes a robust monitoring methodology and criteria setting process, as well as a setting the appropriate system boundary, in terms of environmental indicators and life-cycle stages) and the **administrative burden** this generates for both farmers and the labelling entity.

Both trade-offs impact costs for producers and therefore producer uptake, which is the extent to which firms find it profitable to adopt the label.

Both EU administered labels certify a broad range of environmental indicators, which contributes to their credibility. Such "**holistic**" schemes tend to be better equipped to

[128] Europa.eu, n.d: LIFE project database. Available at: http://ec.europa.eu/environment/life/project/Projects. Accessed on 20 Dec. 2018

avoid conflicts between for instance GHG emission reduction and biodiversity - this is possible for the Ecolabel. Since the EU Organic label does not specifically aim for emission reductions, it cannot currently be said to do the same, but inhibits the potential when integrating CSA-criteria.

Although the efficiency of the new Organic rules applicable from 2021 cannot be assessed at this stage, a lesson learnt from the Organic label is that **control systems** can potentially be loosened strategically (i.e. reducing administrative burden without giving in on credibility). As the fee payed for the annual controls proved costly for many farmers, this was identified as a potential barrier for other farmers to transition to organic farming. These concerns have been taken into account by deploying a risk-based approach to reduce certification costs for farmers who have proved to comply during three consecutive annual controls. In case of the EU Ecolabel on the other hand, the frequency of controls under the EU Ecolabel is determined by the competent authorities, on the basis of their own risk assessment of potential non-compliance. There is thus no harmonised European framework for determining the frequency of controls, but the underlying rationale is based on the assessment of risk and related costs.

The EU-led governance structure facilitates an **EU-wide multi-stakeholder process** for the development of product criteria and production rules, supported by expert bodies.

Involving producers in the criteria development process ideally provides a platform to safeguard producer uptake by ensuring that the proposed production rules and criteria are as stringent as possible (i.e. ambitious) but still practically implementable (i.e. feasible). The stakeholder-based process should on the other hand look into options for verification, which can contribute to lowering data needs. However, the discontinuation of some PEF pilots (see section 4.5.3) and the fact that some of the Ecolabel product groups have very low producer uptake, indicates that a multi-stakeholder process cannot always guarantee successful adoption by the industry when certification is voluntary. The eventual decision on the stringency of the EU Ecolabel's criteria lies with the Regulatory Committee composed of the Member States, which at times leads to industry dissatisfaction with the criteria and low uptake.

In case of the stakeholder driven PEF process, the trade-off between credibility and administrative burden is apparent in the sense that simplifying product criteria can keep industry stakeholders on board as the method's complexity and thus administrative burden will be lower but thereby risking that simpler and fewer criteria will lead to a less robust method for assessing environmental performance (i.e. lower credibility).

In terms of **certification requirements**, the EU Ecolabel imposes a mix of so-called input- and output-based criteria (see section below). The EU Ecolabel's **criteria development process** of both input- and output-based criteria heavily draws on LCA-based evidence provided by the JRC. The Organic label on the other hand mainly imposes input-based requirements and does not have this reliance on LCA-based evidence built in the development of production rules, which ultimately rely on organic principles set by the legislation. In terms of **verification** of Ecolabel applications, the European Commission provides a manual per product group with all data requirements and tests to be performed for the producer to obtain the Ecolabel licence. The Organic label on the other hand requires a registration with an authorised control body which will verify regularly whether the organic rules are being met.

Overall, both labels mainly rely on input or best practice-based criteria[129]. While the European Commission is responsible for developing and reviewing the certification requirements (EU Ecolabel) and setting minimum organic standards (EU Organic label), in collaboration with stakeholders, concrete verification of product application is done at Member State level, checked by independent **third-party verification** bodies, to ensure a credible control system. The administrative **cost of certification** is borne by the producer in the form of a certification fee, but financial (EU Organic label) and administrative support during the application process (EU Ecolabel) is available.

Overall then the study has observed that efforts have been made to balance on the one hand the environmental ambition and feasibility and on the other hand the credibility and administrative costs associated with EU certification initiatives. In practice however, it has proven difficult to balance these considerations as a way to ensure producer uptake. More "holistic" schemes with a looser control system tend to fare better in terms of balancing the efficiency trade-off by reducing costs while maintaining overall credibility.

Certification requirements: input versus output-based criteria

A label's certification requirements specify the criteria that products or production processes have to fulfil in order to be certified. These can be characterised either as input or output-based criteria[130]. **Input-based criteria**, also called practice-based criteria, explicitly define how these criteria should be met by specifying which measures should be adopted or banned. **Output-based criteria**, also called result-based criteria, on the other hand aim to control environmental impacts by setting thresholds on environmental outputs such as GHG emissions without specifying how these should be respected. If these thresholds are respected, an activity's environmental impact will be reduced. By setting such thresholds on GHG emissions, output-based criteria thus guarantee a direct link between compliance (i.e. respecting the limits) and reduced climate impact, provided that the system boundaries are drawn in such a way to avoid spill-over effects to another life-cycle stage. Input-based criteria assume this link implicitly, either based on LCA-based scientific evidence (EU Ecolabel), or on the principles of organic farming (EU Organic label).

Most environmental food labels such as Klimatmärkning, the EU Organic label and the EU Ecolabel mainly set input-based criteria. These are less costly to verify compared to output-based criteria. A compliance check for an input-based criterion can be done by verifying whether the practice is adopted correctly (e.g. restricting or banning the use of a certain fertilizer). For output-based criteria a compliance check needs to measure the environmental output to be reliable.

Regarding the measurement of climate impacts from agriculture, a distinction should be made between the measurement of GHG emission sources and carbon sinks such as soils and woody biomass. While not spared from uncertainties, the direct release of GHG emissions can be measured relatively easily, based on pre-determined emission factors[131]. Climate mitigation from enhancing agricultural carbon sinks on the other hand is more complex as the capacity for carbon storage depends on climate and soil conditions[132]. Estimates rely on soil sampling or on models estimating their indirect effect. These estimates contain significant uncertainties, not the least because the regional soil and climate differences across the EU need to be captured by the model. While Task 2, assessed the EU agricultural sectors' potential for the adoption of some carbon sink enhancement methods for which data is available, this data is scarce at farm level, which hampers monitoring of individual farm carbon sequestration. Since sink enhancing CSA measures such as the use of cover crops represent an important mitigation opportunity

[130] The distinction between input and output-based criteria is based on Sengstschmid et al. 2011.

[131] Lewis et al., 2010: Effective approaches to environmental labelling of food products: University of Hertfordshire, Available at: www.psi.org.uk/pdf/2011/food_labelling/annex_a.pdf

[132] West et al. 2010: Trading carbon for food: Global comparison of carbon stocks vs. crop yields on agricultural lan,. PNAS 107(46):19645–19648. doi: 10.1073/pnas.1011078107.

(see Table 24). the challenge ahead lies in the development of robust, though feasible methodologies that can provide a monitoring, reporting and verification framework for the enhancement of agricultural climate sinks by individual farmers.

The PEF process is one of the current initiatives aiming to address methodological challenges related to both input and output-based criteria. As pointed out in section 4.5.3, following the PEF pilot phase, it can be said that this initiative further clarified the trade-off between methodological robustness and administrative costs. Table 24 below lists the specific advantages and disadvantages of both types of criteria. It indicates that, overall, output-based criteria generate a more robust (i.e. credible) environmental benefit at higher costs, while input-based criteria can reduce administrative and enforcement costs associated with reporting and verification, potentially at the expense of the scheme's environmental benefit.

Table 24 - Advantages and disadvantages of input and output-based criteria[133]

	Input-based criteria	Output-based criteria
Pro	1. Lower data requirements (lower **administrative and enforcement costs**) 2. Actions can be limited to one lifecycle stage (lower **compliance, administrative and enforcement costs**)	1. Higher certainty of **environmental benefit** 2. Flexibility regarding adopted practices (lower **compliance costs**) 3. Broader system boundaries can avoid shift of environmental impact to other lifecycle stage (higher **environmental benefit**)
Contra	1. Lower certainty of **environmental benefit** (no direct link) 2. No flexibility regarding low-carbon practice (higher **compliance costs**) 3. Potential shift of environmental impact to another lifecycle stage (lower **environmental benefit**)	1. High data requirements for direct measurement (higher **administrative and enforcement costs**) 2. Requires collaboration across supply chain[134] (higher **administrative and enforcement costs**) 3. Potentially uncertain models when avoiding direct measurements(lower **administrative and enforcement costs** and lower **credibility**)

When applied to different lifecycle stages, output-based criteria can make sure that producers choose the best combination of practices across lifecycle stages, without shifting the environmental burden to another stage. Input-based criteria cannot avoid this potential trade-off by themselves but need to be set in a predefined combination. Their

[133]Based on Sengstschmid et al. 2011

[134] In case the label certifies emissions across life-cycle stages

focus on applying the best practice in one life-cycle stage (e.g. short supply chains) can lead to avoiding a potential climate benefit from another lifecycle stage. An example here is how tomatoes with a lower climate impact will not be imported to a country where their cultivation is more energy intense (which would reduce overall climate impacts), if there is a label supporting short supply chains[135]. While reporting on input-based criteria thus requires information from several actors in the value chain, their focus on the overall environmental results can avoid trade-offs across lifecycle stages within the same environmental impact category[136], in this case climate change.

Both input and output-based criteria can be applied to one lifecycle stage, but to benefit from the above outlined advantage of output-based criteria, these should feature in a scheme with broader system boundaries (i.e. multiple lifecycle stages).

When applied on farm level (i.e. calculating the overall farm carbon footprint), output-based criteria can avoid a potential side-effect of a label on products with interlinked production systems. Output-based criteria can namely avoid that emission reductions associated with the production process of a certified product (e.g. milk) lead to emission increases in the emission intensity of another product that is not certified (e.g. meat)[137]. This however requires the entire farm to be certified, such as will be the case for the Organic label as of 2021, instead of only the production process related to a specific product.

4.6 Policy options for a climate smart agriculture label

In this section we assess several policy options for the development of a "climate smart agriculture" label. Drawing on the outcomes of the previous sections, we explore potential synergies with existing EU initiatives and investigate which type of certification requirements is best suited to incentivize CSA.

Given that certification requirements determine the most essential costs and benefits of any certification scheme (see section 0 below), we assess the integration of input-based or output-based criteria into existing EU labelling schemes, as well as the development of a new label relying on either input or output-based criteria, or on a mixture of both in a so-called hybrid approach.

The following scenarios for incentivizing CSA practices through a labelling scheme are explored:

1. Integrating **input** and **output**-based CSA criteria into the **EU Ecolabel** (i.e. an EU Ecolabel for farming products)
2. Integrating **input**-based CSA criteria into the **EU Organic label** (i.e. update the organic standards with more climate-oriented requirements)
3. Integrating **input**-based CSA criteria in the **EU Organic label** as **add-on** (i.e. an optional additional certification scheme for organic farmers who aim to adopt CSA practices)
4. Developing a **new input**-based CSA labelling scheme (i.e. a "climate only" low-carbon farming certification scheme)

[135] Sengstschmid et al. 2011

[136] Environmental impact categories such as climate change categorise the impacts of environmental pressures such as GHG emissions

[137] Zehetmeier et al., 2012 Does increasing milk yield per cow reduce greenhouse gas emissions? A system approach. The Animal Consortium

5. Developing a **new output**-based CSA labelling scheme (i.e. a Product Carbon Footprint for farmed products)
6. Developing **a new hybrid** CSA labelling scheme (i.e. a labelling scheme setting **output-based** criteria and measuring **input**)

It should be noted that labelling schemes can be composed of both input and output-based criteria. For conceptual clarity, some of the options explored only rely on one type of criteron to highlight trade-offs between different scenarios, and to assess what it would entail to introduce specific types of criteria as part of new or existing labels. Considerations independent of input or output-based criteria are also taken into account.

Assessment of policy options

The options are assessed by exploring their potential costs and benefits compared to a business as usual scenario. The main aim of this assessment is to illuminate factors driving these costs and benefits and thereby clarifying trade-offs that need to be considered when designing a CSA-label.

Several studies and evaluations assess the costs of specific aspects of certification schemes[138]. The present study does not aim to quantify the certification costs for farmers but points to the relative costs of the options compared to one another.

Below we spell out how costs and benefits of a labelling scheme relate to each other. We then present the policy options and highlight some of the key factors driving these costs and benefits, followed by conclusions.

Costs and benefits

Enforcement costs are borne by the organisation setting up a voluntary certification scheme. These include costs associated with defining and enforcing certification requirements. **Direct compliance costs for economic operators** (i.e. farmers and other actors along the value chain) are costs borne to meet the product criteria, such as investments to change production processes. In addition, economic operators incur **administrative** costs associated with data gathering, reporting and the certification fee payed to control bodies.

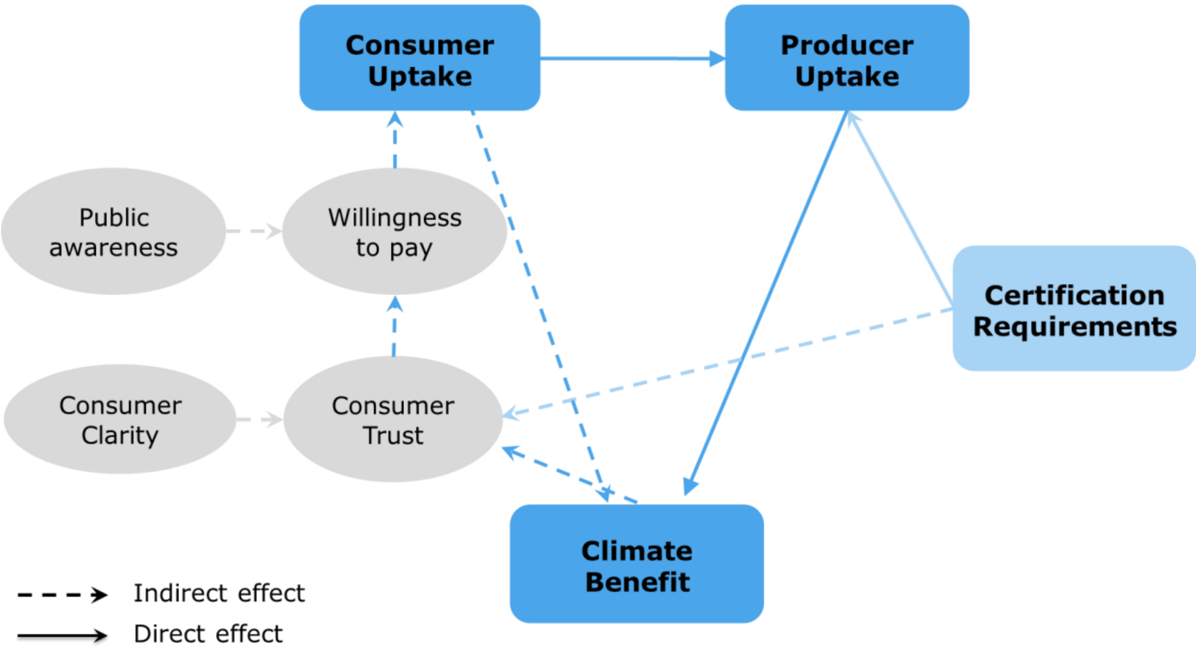
If producers can comply with the certification requirements at a cost that is lower than the **increased revenue** they can expect from (increased) sales on certified products they can sell at a higher retail price, the scheme can create an incentive to adopt climate smart agricultural practices. Therefore, **producer uptake** is essential for a certification scheme to be effective. Expected revenue is determined by assumed **consumer uptake**, which is essentially determined by consumers' willingness to pay for low-carbon products. The literature review on willingness to pay presented in section 4.3.2 indicated that a certain proportion of consumers is willing to pay more for food products with a lower climate impact, but that there is significant consumer confusion due to the proliferation of ecolabels, which might limit consumer uptake as it undermines overall **consumer trust**

[138] Certification fee of the ecolabel for instance varies between 200€ and 2000€ for a one-off application and a maximum of between 18750€ and 25000€ depending on the type and size of firm. (see European Commission, 2019 http://ec.europa.eu/environment/ecolabel/how-to-apply-for-eu-ecolabel.html)
Organic certification costs vary across Member States. The 2013 evaluation indicates that the inspection fee, which is the largest part of certification costs, amounts to 900-1000€ on average per farm (see Sanders, 2013).

in ecolabels. Public awareness of the climate impact of food, as well as the risks posed by a changing climate on the other hand can positively influence willingness to pay[139].

As indicated by Figure 17, consumer clarity (i.e. the inverse of consumer confusion) and public awareness are essentially external factors influencing the costs and benefits of a labelling scheme. Awareness among consumers on the risks posed by climate change contributes to willingness to pay. While a label cannot in itself influence overall consumer willingness to pay, consumer trust in a credible label that ensures climate benefits can contribute to the willingness to pay for this specific label and thus enhance its consumer uptake.

Figure 17 - Interrelation between factors influencing a label's climate benefit



Source: Ramboll Management Consulting

All of the above considerations influence the scheme's main benefit, namely its contribution to net emission reductions by both reducing the release of GHG emissions and enhancing agricultural sinks. A label's **climate benefit** is thus determined by its ability to drive net emission reductions, within defined system boundaries. If sufficient data is available, it can be assessed by multiplying sales (consumer uptake) by expected emission reductions compared to a benchmarked conventionally farmed food product.

Figure 17 furthermore indicates how the type of certification requirements has a direct influence on producer uptake, either by determining actions (input-based criteria), or results that need to be obtained (output-based criteria). The emissions reducing effect of compliance in turn determines a label's climate benefit.

[139] Public awareness does not directly influence consumer trust because awareness of an issue does not directly lead to trust in a specific certification scheme.

An ideal CSA label: balancing ambition and feasibility as well as credibility and administrative burden

An ideal CSA label balances the trade-off between the **environmental ambition** and **feasibility** of the label's certification requirements. In addition, the robustness of the monitoring methodology and related scope of indicators and life-cycle stages finds a balance between the **credibility** and **administrative burden**.

A successful, voluntary low-carbon food label is able to drive emission reductions and will do so at a cost that does not outweigh the benefits for both producers (i.e. increased revenue) and consumers (i.e. increased wellbeing from improved climate quality).

Certification requirements set by the label will be both **feasible** for producers to comply with and sufficiently **ambitious** to reduce emissions compared to conventional farming practices. The compliance costs of implementing these criteria as well as administrative costs will be (partly) passed on to consumers. Consumers are sufficiently aware of the urgency of climate action to be willing to cover this price increase, in exchange for a higher "climate quality" ensured by emission reductions. In this ideal scenario, sufficient data on consumer uptake as well as benchmarked net emission reductions is available to assess its climate impact. In addition, robust models developed to estimate emissions from agricultural practices for different farming types under specific local conditions do not require an unrealistic amount of activity data.

Policy options for a climate smart agriculture label

In order to draw from the experience of existing labelling schemes, the first three options explore the costs and benefits of integrating CSA criteria into the existing EU run labelling schemes. Options 4, 5 and 6 explore possibilities for a new CSA labelling scheme.

Table 25 below outlines the key characteristics of the six policy options.

Table 25 - Policy options for a climate smart agricultural label

	Integration of CSA criteria into existing label			New CSA label		
Policy option / Criteria	1. Integration into EU Ecolabel	2. Integration into EU Organic label	3. Add-on to EU Organic label	4. New Input-based label	5. New Output-based label	6. New Hybrid input/output label
CSA certification requirements	Input and Output-based criteria	Input-based criteria	Input-based criteria	Input-based criteria	Output-based criteria	Hybrid criteria
Scope	Holistic	Holistic	Holistic + Add-on climate indicators	Climate indicators only	Climate indicators only	Climate indicators only
Criteria development basis	LCA based best-practices	LCA based best-practices and organic legislative standards	LCA based best-practices	LCA based best-practices	LCA based best-practices	LCA-based best-practices and standards
Reporting obligations for verification	Data on environmental output and practices	Data on practices	Data on practices	Data on practices	Data on practices and GHG emissions sources and sinks	Data on practices and GHG emissions sources and sinks
Lifecycle stages	Most harmful life-cycle stage (i.e. Agricultural stage)	Agricultural stage	Agricultural stage	Agricultural stage	Agricultural stage, processing, packaging, transport, retail	Agricultural stage
Communication	Ecolabel on food	Organic climate friendly food	Organic climate friendly food	New logo	New logo (PCF on food)	New logo

Integration of CSA criteria in the EU Ecolabel – Option 1

Option 1 entails the certification by the EU Ecolabel of agricultural products, which are currently excluded from the scheme due to concerns regarding consumer confusion, methodological complexity and consumer demands on labelling scope including social and ethical issues.

Concretely, option 1 would have the JRC together with the EU Ecolabelling Board develop both input and output-based criteria for food products, based on LCA-evidence determining environmental hotspots for specific types of farms. As the Ecolabel is a holistic certification scheme, the criteria development process will identify other environmental issues associated with food production, which on the one hand might imply higher costs for producers and on the other hand contribute to its **credibility** avoiding trade-offs between different impact categories. As this standardized procedure is one of the foundations of the label's credibility, it is not advisable to deviate from this process. Theoretically, this option could thus certify a range of environmental issues, as well as all environmental impactful lifecycle stages. Given that agriculture is responsible for the most significant environmental impacts, and about 50% of GHG emissions during the lifecycle of most food products[140], the largest environmental and **climate benefits** will often be achieved in the agricultural sector.

Given that the mechanism selecting product groups for which criteria are developed is built on an LCA-based assessment of most environmental harmful life-cycle stages, in practice option 1 will most likely limit the certification requirements to the agricultural lifecycle stage. It can thus be envisioned that product groups such as fruits and vegetables whose relative environmental impact is higher in other lifecycle stages, will not be considered for certification. Since certifying multiple environmental impact categories over different lifecycles is **complex**, limiting assessment to one life-cycle stage will reduce administrative costs for producers.

Among food products with high impacts during primary production0, a PEF has been developed for dairy products. As pointed out in section 4.5.3 , the PEF process for meat products has not reached completion. Experience with developing both input and output-based criteria is thus growing, which will be further explored during the transition phase and could feed into the criteria development of option 1.

Integration of CSA criteria in the EU Organic label – fully integrated (Option 2) or as add on (option 3)

The organic label is a holistic label addressing multiple environmental but also ethical and social issues, relying on input-based criteria. While some organic practices reduce climate impacts and contribute to climate adaptation (see section 4.5.2), there is currently no formal objective nor obligation of the EU Organic legislation to address climate change. In order to formally integrate input-based CSA criteria into the Organic label (option 3), an explicit objective to contribute to climate mitigation (and potentially adaptation) would have to be incorporated in the Regulation. In order to avoid potential conflicts between climate and organic objectives, such as reduced herbicide use versus mechanical tillage, the current organic standards should be updated assessing both GHG emissions as well as other environmental effects, to include only those practices that are beneficial for both objectives. As the current organic farming production rules do not rely on LCA methodologies to identify best-practices, integrating climate-oriented

[140] Sengstschmid et al. 2011

requirements can be an opportunity to introducing these to organic standard setting and increase credibility.

Option 2 would require all organic farms to adjust their practices to incorporate input-based climate-oriented criteria. Apart from adding organic farming requirements, updating organic standards to reflect climate objectives can also lead to abolishing certain practices, when evidence points to negative climate impacts. While running the risk that some farmers cease their organic cultivation practices when faced with additional criteria, compared to other options the label might still ensure **extensive producer uptake** of current organic farmers.

Option 3 can mitigate this risk by introducing organic CSA labelling as an add-on for organic farmers, such as the Swedish Klimatmärkning label (see section 4.4.2). This way the additional label can be truly voluntary for those farmers who specifically want to integrate climate practices, and the current definition of organic farming can remain unchanged, which implies lower initial enforcement and compliance costs compared to option 2. The trade-off here is the risk of potential consumer confusion regarding the difference between 'pure' organic and 'organic low-carbon' farming and the additional label required for the latter. However, as many consumers currently assume organic farming is climate-friendly[141], spelling out this difference can potentially reduce confusion.

A substantial risk of option 3 is that organic farmers do not see the benefit of additional certification. It should indeed be investigated whether there is willingness to pay for organic climate-friendly products, and whether increased sales could generate sufficient additional revenue in order to avoid an additional price difference between pure organic and organic climate friendly products.

A new CSA label – Options 4 (input-based), 5 (output-based) and 6 (hybrid approach)

A new CSA label applicable throughout the EU would only incorporate criteria related to the climate impact of a product.

Option 4 would be a low-carbon farming certification scheme relying on input-based criteria, focusing on the climate impact generated during the agricultural life-cycle stage. By adopting input-based criteria only and focussing on agricultural processes, administrative costs can be significantly reduced.

Relying fully on output-based criteria, option 5 would provide the basis for a full Product Carbon Footprint labelling scheme for farmed products. By measuring the GHG emissions of a benchmark product it would assess the climate impact of all life-cycle stages and provide information on the relevant performance of the product to consumers. The high data requirements for direct measurements to calculate this footprint lead to extensive administrative costs.

Due to diverging local climatic, biophysical, social and economic conditions impacting for instance the availability of water or land etc. for all options it proves challenging to predefine the right combinations of criteria that would lead to an environmental benefit when applied in the multiple types of farms across the EU.

Option 6 aims to address this challenge. Instead of relying on separate input or output-based criteria based on predefined organic farming rules (options 2 and 3) or environmental excellence criteria established through generic LCA studies (options 1, 4 and 5), a farm-level carbon calculator can identify the mitigation potential of the ideal

[141] Sengstschmid et al. 2011

combination of practices for a *specific* farm. Within the boundaries of the ambition levels set by the labelling statutes, the label can tailor the requirements to the feasibility of the specific farm.

By means of farm-specific emission factors, it is possible to arrive at an estimation of environmental outcomes that can be compared across different farms. The control system only verifies the adoption of practices and does not require data on specific outcomes, which significantly lowers data requirements compared to option 5.

Here the main challenge is to identify the right emission factors for each relevant practice on all types of farms. As outlined in section 4.5.7, there is currently a lack of accurate data for assessing GHG emissions from sinks, which can complicate the assessment of soil enhancing practices. Furthermore, data on practices as assessed for the Netherlands in Task 2 is not available for each Member State.

In case data is available and models for assessing are improved, this option would score well on credibility, while enforcement and administration costs would not be higher than for the other options. As for option 4, the label requirements can be set based on data availability and associated administrative costs of data gathering.

Below we highlight several key considerations illuminating costs and benefits of the selected policy options.

Key factors driving costs and benefits

Data requirements: input versus output-based labels

Data requirements for monitoring, reporting and verification of input-based criteria are generally lower compared to output-based criteria, which require more sophisticated and often unreliable measurement techniques, for instance to account for carbon sequestration. Schemes solely setting input-based criteria (options 2, 3 and 4) thus generate less administrative and enforcement costs on this front compared to the other options.

As spelled out in section 4.5.7, when setting appropriate system boundaries output-based criteria can guarantee emission reductions by setting GHG emission thresholds. However, in case emission reductions from carbon sinks are to be taken into account, robust though affordable methodologies should be developed – potentially based on remote sensing - to allow farmers to report emissions stored in their soils and woodlands when applying for certification.

By introducing input-based criteria that focus on the agricultural lifecycle stage alone, option 4 can develop criteria specifically designed to minimize data requirements, which will greatly reduce enforcement and compliance costs as compared to the other options.

When adding CSA criteria to the organic label (option 2 and 3), some criteria might rely on data that is already gathered for other reporting obligations, either under the organic legislation itself, or in the context of other policies such as the Common Agricultural Policy (CAP) greening measures. Here it should be noted that this cost reduction will only correspond to a higher climate benefit if the certification requirements incentivize additional measures and do not duplicate what is required by these other policies.

Governance structures: existing EU labels versus new labelling schemes

Given that the EU Ecolabel and Organic label have **governance structures** in place for monitoring, reporting and verification (MRV), as well as for the development of the labels' certification requirements, it could be expected that both enforcement and administrative costs associated with MRV are initially lower for options 1, 2 and 3 (existing labels) than for options 4, 5 and 6 (new labels).

Gains can be expected from the well-established criteria development and review procedure under the EU Ecolabel, which can easily establish standardized emission factors for the measurement of GHG emissions sources (option 1). Regarding the monitoring of sinks, this is possible as well but given that there is currently no full farm-level database covering GIS data on agricultural sinks (see Task 1) this will have to rely on models aiming to attribute reductions from sinks to specific products, with significant uncertainties as a consequence.

While this would need to be substantiated by looking into verification procedures, the additional certification fee organic farmers would pay to obtain the organic add-on label, could potentially be lower under options 2 and 3 than for the other options as verification could potentially be done simultaneously with organic certification.

Consumer trust: an issue for all labels

In order to assess potential **consumer uptake**, the differences between a holistic scheme (options 1, 2 and 3), or a "climate only" labelling scheme (options 4, 5 and 6) come into play. Both the development of a new carbon food label, as well as integrating climate concerns into existing schemes can generate consumer confusion. A new label is confronted with the difficulty of gaining a credible reputation among the many competing environmental claims. An existing holistic scheme incorporating climate criteria, runs the risk of failing to be seen by consumers as reducing climate impact due to its association with other issues. In both cases, information campaigns are advisable. These should not only highlight the specificities of the respective label, but should also concern the climate impact of food products in general. In this regard, "climate only" labels have the advantage of communicating one clear message – this label guarantees low-carbon production - over holistic labels who need to communicate about a whole range of environmental impacts. However, when assessing consumer trust and credibility in the broader sense, the existing holistic schemes (options 1, 2 and 3) have the advantage of on the one hand avoiding trade-offs between different environmental issues, and relying on the established credible reputation of the EU Organic and Ecolabel on the other hand. Furthermore, one of the reasons not to include food products into the EU Ecolabel was that consumers expect food ecolabels to cover social and ethical concerns as well[142]. Since these are partly covered by the organic label, options 2 and 3 could be expected to increase consumer trust.

While Option 5 is equipped to communicate the quantified carbon footprint of a specific product as part of the PFC label's logo, it should be noted here that consumers tend to have difficulties interpreting a number that indicates the amount of GHG emissions released during production. A quantified carbon footprint should be compared to other products in order to provide meaningful information about a product's relative climate impact.

Based on the above considerations Table 26 below summarizes the factors that influence the effectiveness and efficiency of each label and points to potential issues that need to be taken into account when developing a CSA label.

[142] Sengstschmid et al. 2011

Table 26 - Factors influencing the effectiveness and efficiency of the policy options

		1. Integration into EU Ecolabel	2. Integration into EU Organic label	3. Add-on to EU Organic label	4. New Input-based label	5. New Output-based label	6. New Hybrid input/output label
Effectiveness	Climate ambition	• Criteria development process can set high ambition	• Potential to mitigate conflicts between climate and organic farming objectives	• Potential to mitigate conflicts between climate and organic farming objectives	• Potential to set high standards	• Potential to set high standards	• Ambition can be adjusted to farm
	Feasibility of compliance	• High ambition can lead to reduced producer uptake • Flexibility of investment decisions for output-based criteria can reduce compliance costs	• Potential for high producer uptake compared to other options • Risk of reduced producer uptake for organic farming	• Risk of low producer uptake	• High ambition can lead to reduced producer uptake	• High ambition can lead to reduced producer uptake • Flexibility of investment decisions can reduce compliance costs	• Feasibility can be tailored to farm
Efficiency		**Factors enhancing credibility**					
	Credibility of monitoring methods	• Holistic	• Holistic • Introduction of LCA-based methodologies	• Holistic • Introduction of LCA-based methodologies	• Generic LCA based selection of climate hotspots	• Quantified output • Verifiable emission reductions	• Quantified output • Mitigation actions tailored to farm

	1. Integration into EU Ecolabel	2. Integration into EU Organic label	3. Add-on to EU Organic label	4. New Input-based label	5. New Output-based label	6. New Hybrid input/output label
	• Standardized criteria development process • Assessment of most harmful life-cycle stage • Potential to avoid trade-off with other environmental indicators	• Potential to avoid trade-off with other organic objectives	• Potential to avoid trade-off with other organic objectives			based on farm carbon calculator
			Factors reducing credibility			
	• Generic LCA based selection of environmental hotspots	• No direct link between compliance and emission reduction • Risk of shifting environmental burden to other lifecycle stages • Only generic LCA based selection of climate hotspots	• No direct link between compliance and emission reduction • Risk of shifting environmental burden to other lifecycle stages • Only generic LCA based selection of climate hotspots	• Risk of trade-off with other environmental indicators • No direct link between compliance and emission reduction Risk of shifting environmental	• Risk of trade-off with other environmental indicators	• Risk of trade-off with other environmental indicators • Risk of shifting environmental burden to other lifecycle stages

	1. Integration into EU Ecolabel	2. Integration into EU Organic label	3. Add-on to EU Organic label	4. New Input-based label	5. New Output-based label	6. New Hybrid input/output label
				burden to other lifecycle stages		
Adminisrative burden	**Factors increasing administrative burden**					
	• Data needed on multiple environmental indicators • Complex monitoring mechanisms for output-based criteria	• Reducing			• Complex monitoring and verification of PCF • Assessing multiple life-cycle stages	• Need for • Limited data and reliable models for assessing GHG emission sources and sinks
	Factors reducing administrative burden					
	• Existing governance structure • No complex monitoring mechanisms for input-based criteria • Most likely assessment of	• Existing governance structure • Assessment of only one lifecycle stage • Only additional data needed on one environmental indicator	• Existing governance structure • Assessment of only one lifecycle stage • Only additional data needed on one environmental indicator	• Assessment of only one lifecycle stage • Single environmental indicator to monitor • No complex monitoring mechanisms	• Single environmental indicator to monitor	• Single environmental indicator to monitor • Assessment of only one lifecycle stage • No complex monitoring mechanisms

	1. Integration into EU Ecolabel	2. Integration into EU Organic label	3. Add-on to EU Organic label	4. New Input-based label	5. New Output-based label	6. New Hybrid input/output label
	only one life cycle stage	• Potential to use data gathered for other reporting obligations • Potentially lower certification fee • No complex monitoring mechanisms	• Potential to use data gathered for other reporting obligations • Potentially lower certification fee • No complex monitoring mechanisms	• Certification requirements can be adjusted to minimize data requirements		
Consumer uptake	• Benefits from Ecolabel's reputation • Risk of diluted message	• Benefits from Organic label's reputation • Covers social and ethical concerns • Risk of diluted message	• Benefits from Organic label's reputation • Covers social and ethical concerns • Potentially less consumer confusion by clarifying difference between organic and climate	• Risk of consumer confusion • Benefit of clear communication on low-carbon production	• Risk of consumer confusion • Benefit of clear communication on low-carbon production • Difficulty for consumers to interpret quantified PCF	• Benefit of clear communication on low-carbon production

4.7 Task 3 Conclusions

The development of an effective labelling scheme is a balancing exercise between setting **feasible** certification requirements that can be attained by producers on the one hand and can drive sufficient climate **ambition** on the other hand.

The efficiency of a label is determined by the balance between on the one hand their **credibility**, which includes a robust monitoring methodology and criteria setting process, as well as a setting the appropriate system boundary, in terms of environmental indicators and life-cycle stages, and on the other hand the **administrative burden** this generates for both farmers and the labelling entity.

Among the policy options assessed, the option proving most promising in terms of balancing feasibility and ambition is the hybrid approach. This is due to its farm specific carbon calculator that can assess the context-specific mitigation potential of the production processes determining farm specific climate-smart practices. Standardized emission factors can provide quantified estimates of GHG emission outputs. However, in order to capture all relevant climate impacts associated with agricultural production for local farming conditions, including carbon sequestration, more robust models need to be developed.

The options highlighting potential reductions of administrative burden include the new CSA label relying on input-based criteria, and the integration of CSA criteria into the EU Organic label. The new input-based certification scheme only assesses climate impacts. Compliance is relatively easy to verify as it only requires data to demonstrate the adoption of CSA practices. Furthermore, the label can set criteria specifically designed to minimize data requirements, which will minimize enforcement and administrative costs. However, as these practices will be selected based on generic LCA evidence, the lower administrative costs are met with lower credibility. The integration of CSA criteria into the Organic label can potentially gain from reduced data gathering needs when relying on data that has already been collected for other purposes. In addition, by pooling control visits with those carried out for organic certification, the inspection fee could be relatively lower than for other options.

All certification schemes risk to be confronted with the consequences of consumer confusion due to the proliferation of environmental claims, which would need to be countered by clear communication on both the purpose and benefit of the scheme, as well as the climate impact of food in general.

Conclusions

Task 1 found that overall, activity data that can be related to climate smart agriculture measures is widely available. Data on land use and land cover in particular as well as energy use is available from specific data sources. Given that different data sources are not completely consistent in how they define different types of land use and land cover, combining data on these areas from different sources may lead to accuracy issues.

Data on the results of the implementation of climate smart agriculture measures is scarcer and - if available - tends to be of lower quality. Results linked to water reduction measures can be derived from data on irrigation, whereas results from CSA measures related to the reduction of GHG emission or sequestration of soil organic carbon can only be derived from model-based estimations. GHG emissions at farm level are not measured by default, and while soil organic carbon (SOC) stocks have been measured regularly across the EU since 2009 through LUCAS sampling, the strategy does not allow for an estimation of SOC stock changes in a sufficiently accurate manner[143]. SOC changes over the course of the considered timeframe are likely to be smaller than the total measurement error.

Based on a literature review, three tools were identified that might provide the potential to calculate farm level greenhouse gas balances using existing data: EX-ACT, Farm Carbon Calculator, LC-Farm.

Deeper investigation of the tools identified in Task 1 demonstrated a significant lack of suitable data. **Task 2** found that the Farm Carbon Calculator (FCC) calculates a more detailed and more comprehensive account of carbon sequestration than LC-Farm and explicitly includes agrochemicals. LC-Farm is more detailed on management practices, includes GHG emission related to cooling and considers organic matter exchange with other farms. Although the tools both include livestock herd size manure production and feed and forage usage, the activity data required differ considerably between the tools. Reason for the large data gaps is that both tools were meant to allow farmers to investigate their own GHG emissions and to act themselves. Consequently, many of the data required do not fall under a reporting obligation. If tools with a level of thematic detail comparable to FCC and LC-Farm are desired by the Commission, regulations regarding data sharing and harmonization have to be set.

The EX-ACT tool can calculate emissions origination from land use changes and crop changes at a Tier 1 level with reasonable reliability. Some of the data can be derived directly and at the right scale from existing data sources. A major uncertainty is introduced by the focus on land degradation, which does not fully match the available data. At European level, exploration of the GHG accounting tool also indicated a level of thematic detail that was too high when compared to data that is available in practice. To get an overview of the CSA status of the EU territory, a data harmonisation step was carried out and three groups of indicators were developed.

A calculation of the level of uptake of CSA measures at NUTS2 level, demonstrated that a few regions in northern Italy have the most widespread implementation of climate smart agricultural practices. These cover cropland management, irrigation, land cover, as well as livestock numbers. A few scattered regions show widespread implementation of three of the four categories, while large areas of central Europe demonstrate little implementation of climate smart practices. Italy, Western England, Ireland and Central

[143] Panagos, P., et al. (2013). "Estimating the soil organic carbon content for European NUTS2 regions based on LUCAS data collection." Science of the Total Environment.

France have widespread implementation of both adaption and mitigation practices, whereas in Spain for example the spread of adaptation practices is low.

An inventory of the level of uptake of 10 CSA measures using FADN data demonstrated that there is large potential for further uptake. Only 5% of land-based farms grow catch crops according to the FADN classification, while the use of permanent grasslands is relatively widespread, with 66% of the farms that could potentially implement the measure actually doing so. When assuming a benchmark of the median area percentage of the farm UAA that is dedicated to the measure, this leaves a potential implementation area of measures of up to 637 thousand km^2 for permanent crops, and between hundred and 200 thousands of km^2 for most other measures. The potential for biofuel crops is around 70 thousand km^2, while the potential for combining permanent and annual crops is just 2500 km^2.

Task 3 assessed policy options for the design of a certification scheme incentivising climate smart agriculture. To design a credible, sufficiently ambitious label, based on robust methodologies and trusted by consumers, that can at the same time set feasible certification requirements farmers can comply with at a cost that does not outweigh the expected revenue from certified products, the analysis points to two essential trade-offs.

Labelling initiatives on the one hand need to balance **ambition** (i.e. setting environmentally stringent product criteria that can foster the label's reputation for environmental protection) and **feasibility** (i.e. setting product criteria producers can meet at reasonable compliance costs). A right balance of this "effectiveness trade-off" should ensure the label's effectiveness.

The "efficiency" trade-off balances on the one hand a label's **credibility**, which includes a robust monitoring methodology and criteria setting process, as well as a setting the appropriate system boundary, in terms of environmental indicators and life-cycle stages, and on the other hand the **administrative burden** this generates for both farmers and the labelling entity.

Among the policy options assessed, the option proving most promising in terms of balancing feasibility and ambition is the hybrid approach. This is due to its farm specific carbon calculator that can assess the context-specific mitigation potential of the production processes determining farm specific climate-smart practices. Standardized emission factors can provide quantified estimates of GHG emission outputs. However, in order to capture all relevant climate impacts associated with agricultural production for local farming conditions, including carbon sequestration, more robust models need to be developed.

The options highlighting potential reductions of administrative burden include the new CSA label relying on input-based criteria, and the integration of CSA criteria into the EU Organic label. The new input-based certification scheme only assesses climate impacts. Compliance is relatively easy to verify as it only requires data to demonstrate the adoption of CSA practices. Furthermore, the label can set criteria specifically designed to minimize data requirements, which will minimize enforcement and administrative costs. However, as these practices will be selected based on generic LCA evidence, the lower administrative costs are met with lower credibility. The integration of CSA criteria into the Organic label can potentially gain from reduced data gathering needs when relying on data that has already been collected for other purposes. In addition, by pooling control visits with those carried out for organic certification, the inspection fee could be relatively lower than for other options.

All certification schemes risk to be confronted with the consequences of consumer confusion, which would need to be countered by clear communication on both the purpose and benefit of the scheme, as well as the climate impact of food in general.

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Annexes

Annex 1: Evaluation of Farm Carbon Calculator tool inputs

Carbon sequestration

Data on orchard areas, subdivided into different classes (top fruit, stone fruit, nuts) are needed and were taken from the FADN database. Existing spatial data does not meet the thematic resolution required by the tool. The tool contains different sequestration factors for different fruit tree types, resulting in differences in sequestration level. Vineyard data can be taken from a variety of data sources. For the sake of consistency with orchard data, as far as relevant, FADN data were adopted.

The area of woodland and uncultivated data is available from FADN. Data with a higher temporal resolution is available from experimental EO data (eventually ~weeks revisit time) and from annual Dutch crop parcel registration data. Single trees can be identified from the Dutch Natural Capital Atlas. Data on hedges is not readily available at country level but can be derived with a reasonable accuracy from tree and shrub maps from the Dutch Natural Capital Atlas. Additionally, Utrecht province has a detailed map of small landscape elements (SLE). These maps provide areas, which can be easily converted in the length and average width required by the tool. Additionally, experiments with mapping hedgerows from radar imagery are ongoing. At a pan-European scale, a high-resolution layer of small woody features is due soon. This layer will likely show the area percentage of small woody elements in 100m resolution grid cells[144]. Uncultivated field edges are in the Parcel dataset of the Netherlands and the area per farm can be extracted from this through a spatial overlay. The area of wetland within a farm can be derived from a high-resolution wetland map (Copernicus), while also the Dutch Land Cover Database contains data on wetlands. For all aforementioned land cover component, the FCC has a specific sequestration factor that is multiplied with the activity data entered in the tool to result in an emission calculation.

Additionally, the FCC can consider loss of soil organic carbon. This is accounted for based on soil organic matter sampling data. The FCC tool requires data on soil organic matter percentage, in two subsequent years, acquired from soil samples. The inclusion of soil data is not compulsory for calculation, but the tool allows up to 10 sets of soil organic carbon parameters to be included. No rules or guidance on an optimal number are given; this calculation is completely data driven. These data can be approximated using soil carbon data. Soil carbon data is available from the Atlas Natural Capital at the level of soil units. Soil carbon can be converted into soil organic matter by multiplying by 44/12 and standard bulk densities for each soil type can be adopted from the tool. Carbon balance data are available from the Atlas Natural Capital, but only at

[144] Copernicus, 2018: High Resolution Layers. Available at: https://land.copernicus.eu/pan-european/high-resolution-layers. Accessed 13.12.2018

municipality resolution. The minimum mapping unit of Dutch soil data is 3000m^2, while the average mapping unit is 66.7 ha. Compared to the farm size in the study region, this spatial resolution lacks the detail for a farm level analysis. An alternative also applicable at European scale would be to build on the LUCAS estimate of soil organic carbon stocks. Although this map displays soil organic carbon stocks at a 100m resolution, this is the result of spatial interpolation of LUCAS soil sampling, which is performed in 20 000 locations throughout Europe. In 2012, 200 samples were collected in the Netherlands, meaning that every sample location would represent 220 ha. A current problem is a lack of time series of LUCAS soil data, but the LUCAS soil sampling component has been continued, meaning that time series with a 3-year revisit time will emerge.

Altogether, soil organic carbon proxies have large uncertainties. For the sake of using consistent data, an average soil organic carbon stock was calculated using the farm perimeter and the soil carbon map from the Atlas Natural Capital. This was translated into soil organic matter. Changes were derived from overlaying the farm perimeter with the carbon balance map.

Livestock

Data on farm animal heads are available from multiple sources. Basically, data are either based on annual national scale statistics, or on FADN / FSS combined survey efforts, and are also included in official Dutch farm reporting systems. In this study, we used FADN data, as detailed in Annex 1: Evaluation of Farm Carbon Calculator tool inputs. The FCC tools uses these activity data to calculate livestock related GHG emissions, using Tier 1 / Tier 2 emission factors that are animal specific.

The Farm Carbon Calculator also needs data on manure handling. While the Dutch official farm reporting systems requires reporting of manure handling, the Farm Carbon Calculator requires the percentage of manure utilized as slurry, farmyard manure, daily spread, in field. This should be specified for each animal class, while national reporting requires a similar distribution over utilization methods by animal breed only. Use of this data is (strongly) restricted for public use.

Finally, the Farm Carbon Calculator requires a detailed account of feed data. These are also part of the compulsory Dutch farm administration, but the Farm Carbon Calculator requires more detail than the compulsory reporting. Availability of manure and feed data is different in different countries. Defra (UK) for example surveys the type of manure that farms apply[145], while it is required for UK farms to keep a record of their feed.

[145] Gov.uk, 2018: British Survey of fertiliser practice dataset. Available at: https://www.gov.uk/government/statistical-data-sets/british-survey-of-fertiliser-practice-dataset. Accessed 10.10.2018.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
1	Carbon sequestration	Orchard area, subdivided into top fruit, stone fruit, nuts, hectares	FADN crop areas (KxxxAA; 152, 341, 349, 350, 351, 356, 357)		Spatially explicit data from the Dutch parcel registration system or from experimental earth observation crop data (sen4cap) do not always provide enough thematic detail.
2	Carbon sequestration	Vineyards; grapevines, hectares	FADN crop areas (K155AA)		
3	Carbon sequestration	Hectares of mixed woodland, short rotation coppice	Parcel Registration map (NL) Atlas Natural Capital NL	http://www.atlasnatuurlijkkapitaal.nl: Basisregistratie gewaspercelen	Provides area of woodland and a few forest categories, that matches the short rotation coppice.
4	Carbon sequestration	Single trees (number and crown area m2)	Atlas Natural Capital NL	http://www.atlasnatuurlijkkapitaal.nl: Basisregistratie gewaspercelen	Tree map from Natural Capital Atlas. Provides % of cell covered by trees > 2.5m. Through grouping of cells, individual trees can be identified and from the percentage and the 10m grid size the area can be calculated.
4	Carbon sequestration	Hedgerows (length, average width; m)	Atlas Natural Capital NL	http://www.atlasnatuurlijkkapitaal.nl	Tree / shrub map, with a 10m resolution.
5	Carbon sequestration	Uncultivated field margins (m2)	Parcel Registration map (NL)	http://www.atlasnatuurlijkkapitaal.nl: Basisregistratie gewaspercelen	
6	Carbon sequestration	Wetlands	Wetlands map, COPERNICUS	https://land.copernicus.eu/pan-european/high-resolution-layers/water-wetness/view	Classes (2) temporary water, (3) permanent wetness and (4) temporary wetness
7	Carbon sequestration	Soil organic matter content (%) and changes therein	Atlas Natural Capital NL soil organic carbon and SOC balance map; bulk density map JRC	http://www.atlasnatuurlijkkapitaal.nl	Balance map contains an aggregated figure at statistical unit resolution. Bulk density map only has a 1km resolution.
8	Distribution	Delivery distance (van, small lorry, large lorry, other)	No data		To the point of sale. Only if transported by an external party.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
10	Distribution	Journeys per year (van, small lorry, large lorry, other)	No data		
11	Distribution	Weight carried per year (van, small lorry, large lorry, other)	No data		
12	Waste	Requires tonnes of waste put into landfill and recycling. Subdivides into 18 categories of waste, including batteries, cans, general waste, tyres, food waste, paper, plastics, electrical items.	No data		
13	Livestock	Number of heads, 23 categories	FADN	FADN D22-D50	More detailed categorization of livestock than available in statistics. Includes for example deer stags and hinds <> deer calves.
14	Livestock	Manure handling: percentage of manure that goes into slurry – farmyard manure – daily spread – in field, on an annual basis, for each of the 23 categories	NL National Statistics / Netherlands Environmental Assessment Agency keep public time series, however not meeting the thematic detail from the tool. Time series is based on official manure reporting at the RVO (Netherlands Enterprise Agency). These data were not available to other parties and also don't meet the thematic detail required by the tool.	CBS, PBL, RIVM, WUR (2018). Mestproductie door de veestapel, 1986-2017 (indicator 0104, versie 20 , 20 maart 2018). www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; en Wageningen University and Research, Wageningen.	
15	Livestock	Imported feed to the farm; 6 categories of organic feed and 11 categories of non-organic feed.	This is part of compulsory Dutch farm level registration, however not at the thematic detail required by the tool.	https://www.rvo.nl/onderwerpen/agrarisch-ondernemen/mestbeleid/mest/mestadministratie-en-registratie/administratie-agrarische-bedrijven	FADN additionally includes costs for purchasing feedstuff.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
16	Agro chemicals	Fertiliser: 19 categories of nutrients in kg per year	Data are part of compulsory Dutch farm level registration, however not at the thematic detail required by the tool. Aggregated N / P / K figures can be used as a proxy.		
17	Agro chemicals	Fungicide, growth regulator, herbicide, insecticide kg per year	NL National Statistics surveys every 4 year. No compulsory reporting.		
18	Fertility	Annual yield of 16 arable and horticulture crops	Standard part of FADN statistics; no compulsory annual reporting; part of annual Eurostat / NL statistical office surveys	FADN K120-K375 QQ	
19	Fertility	Compost produced / bought; tonnes fresh weight	Part of compulsory Dutch farm level registration		
20	Fertility	Lime and mineral fertilizers (tonnes)	Mineral fertilizers are part of compulsory Dutch farm level registration. To my best knowledge, no data on lime available.		
21	Fertility	Plant raising media: Litres used of 9 categories of plant raising media, including 3 categories of peat, bark, wood fibre, vermiculite	Not part of any compulsory reporting and to my best knowledge, no data are available.		
22	Fertility	Hectares of cultivated peat soils	Based on Spatial linkage of farm perimeter (provisional data; from LPIS eventually) and soil data	Soil map D. de Brogniez, C. Ballabio, A. Stevens, R. J. A. Jones, L. Montanarella and B. van Wesemael (2015). A map of the topsoil organic carbon content of Europe generated by a generalized additive model. *European Journal of Soil Science*. 66(1): 121-134, doi: 10.1111/ejss.12193,)	

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
23	Fertility	Hectares and purity of 13 green manure crops	Based on spatial linkage of farm perimeter (provisional data; can be derived from LPIS eventually) and parcel data	http://www.atlasnatuurlijkkapitaal.nl: Basisregistratie gewaspercelen	Purity is not available. Parcel data includes 8 out of 13 green manure species, as well as two "other" classes, one on leguminous and one on not leguminous, which allows a solid approximation of this topic.
24	Capital items	Road vehicles: Euros spent on new vehicle	No data		
25	Capital items	Farm machinery: Horse powers of tractor, combine harvester, forage harvester, fore end loader, potato harvester, sprayer (<10 years)	No data		
26	Capital items	PTO-powered and non-PTO-powered implements (<10 years)	No data		
27	Capital items	Amounts of asphalt, sand, concrete, cement and stone used (<10 years)	No data		
28	Capital items	Amounts of bricks and tiles used (<10 years)	No data		
29	Capital items	Amounts of steal, lead, copper, aluminum used (<10 years)	No data		
30	Capital items	Amount of timber used (<10 years); if available split-up into pine/spruce, plywood, mdf	No data		
31	Capital items	Fencing (<10 years): number of round and half round fence posts and kg wires	No data		
32	Capital items	Other building materials (<10 years old): glass, window units, insulation, aluminium, fiberglass, decorating	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
33	Capital items	Water pipes of HDPE, LDPE, PVC, if available by size category; meters (<10 years)	No data		
34	Capital items	Water systems: weight of storage tank and liner (<10 years)	No data		
35	Capital items	Renewable energy installations: square meters, and amount of aluminium, steel and concrete used for installation (<10 years)	No data		
36	Capital items	Horticultural constructions: Glasshouses, polytunnel frames (if possible by width in 7-8 categories) and their covers	No data		
37	Buildings, machinery and materials	Asphalt, concrete, cement, stone used over the past 12 months	No data		
38	Buildings, machinery and materials	Bricks and tiles used over the past 12 months	No data		
39	Buildings, machinery and materials	Steel, lead, copper, aluminium used over the past 12 months	No data		
40	Buildings, machinery and materials	Timber, pine/spruce, plywood and mdf used over the past 12 months	No data		
41	Buildings, machinery and materials	Number of Round and half round fence posts and kg of wire used over the past 12 months	No data		
42	Buildings, machinery and materials	Water pipes of HDPE, LDPE, PVC, if available by size category; meters used over the past 12 months	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
43	Buildings, machinery and materials	Packaging consumables: plastic, paper and plastic bags, cardbuard and polystyrene boxes, bale wrap in 2 sizes, pallet wrap, quantities used over the past 12 months	No data		
44	Buildings, machinery and materials	Agricultural consumables: twine, silage sheet, net wrap, general plastic quantities used over the past 12 months	No data		
45	Buildings, machinery and materials	Horticultural fleece, netting, ground cover and sheeting in different sizes, quantities used over the past 12 months	No data		
46	Buildings, machinery and materials	Office materials (paper) used over the past 12 months	No data		
47	Buildings, machinery and materials	Tyres for road vehicles and farm machinery, quantities used over the past 12 months	No data		
48	Buildings, machinery and materials	Water use – main and sewage treatment over the past 12 months	No data		
49	Fuel	Gas fuels: consumption of LPG, butane, natural gas, propane and biogas over the past 12 months	No data		
50	Fuel	Solid fuel: consumption of wood logs, chips and pellets, straw/grasses, coal over the past 12 months	No data		
51	Fuel	Electricity: Consumption from renewable, non-renewable, and partly renewable sources over the past 12 months	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
52	Fuel	Liquid fuels: consumption of red diesel, road diesel, petrol, biodiesel, heating oil, and lubricants over the past 12 months	No data		
53	Fuel	Transport by road travel: mileage over the past 12 months and engine size used	No data		
54	Fuel	Transport by public transport; rail, bus, taxi, air (UK, Europe, Rest of World) mileage over the past 12 months	No data		
55	Fuel	Diesel fuel consumption by contractors over the past 12 months	No data		

Annex 2: Evaluation of LC-Farm inputs

Livestock

The **Livestock** module can handle data about 9 main categories of livestock. Each category contains up to ~10 sub categories. For each sub category data is required on number of animals and changes therein over the year, quantities of end products produced, live weight of animal categories, forage and feed practices and quantities, manure management. For all these factors, Tier 2 emission factors are present that are used to calculate greenhouse gas balances.

For the dairy sub category, 9 sub categories of cattle should be distinguished according to weight of dairy cows, age of heifers, as well as bulls and young calves. The tool requires the percentage of the year that cattle is grazing. These data can be accurately be approximated from obligatory reporting data as well as from FADN or FSS statistics. Weights are not regularly reported; however, indicative average weights can be used from either the LC-farm tool or based on e.g. FSS averages. Quantity of milk production is also part of compulsory reporting and is in FADN figures. Figures on protein and fat content are not readily available. Dairy cooperatives regularly report on protein and fat content, but it is not possible to relate this back to specific farms and is commercial data of limited availability. In this study, LC-Farm is parameterized with average figures. Based on the size of the dairy producing cows, milk production per cow is calculated, though, often deviating from actual figures occur by approximately a factor 5.

Forage and feed production and purchase are part of obligatory farm level administration. As there are no regulations regarding the exact way of registering forage and feed, there are differences between farms in registration methods and categories administered, making cross-farm comparison unreliable. The LC-Farm tool requires a high level of thematic detail in registering forage and feed and data at this level of accuracy are regularly not available. Data on forage and feedstuff are needed at the level of the herd of each main category of livestock. Given the lack of available data that fits the tool, this component was disregarded.

The manure management system allows 6 different systems and the tool has parameterized 18 different systems. These data can be approximated based on obligatory farm reporting, although categories do not match. Consequently, the categories were disregarded.

For the other groups of animals, similar data are required. Generally, livestock numbers and changes therein, as well as broad figures on outputs, are readily available from multiple data sources. Details on animals and production quality are not available. The level of detail required by the tool with regard to feedstuff and forage intake is not matched by any data source and data on manure management does exist in the Netherlands, but is untraceable. Consequently, this was currently not included in the tool explorations. If a tool with this level of thematic detail would be desired by the Commission, regulations regarding data sharing and harmonization have to be set.

Crop production

For **crop production,** the LC-Farm tool allows the introduction of 50 crops. For each crop a limited number of variables is compulsory, a large set of optional data can be entered. Areas of each crop are available from a variety of sources, including FADN and Dutch parcel statistics. In current efforts to calculate GHG balances with LC-Farm, parcel statistics were adopted. At EU scale, data are largely lacking. Spatial explicit data allow distinguishing between crop production on organic soils versus mineral soils. Yield data are hugely incomplete. Although part of FADN reporting, there are many data gaps. At EU level, also FSS and annual reporting data are incomplete. Near-future sentinel efforts provide a larger potential to provide more detailed crop data, grassland management data, and yield data. The use of organic manure is, in the Netherlands, known at farm level, but not at parcel level. Compulsory data on the use of machinery is lacking. Annual spending on fertilizers and pesticides are only available through FADN.

Optional data include issues that are important to CSA, such as details on irrigation and soil management. Here, data availability is a strong limiting factor. FADN only provides some basic figures on irrigation and other required irrigation data is only available through LUCAS, which does not allow details beyond NUTS2 level. Data on soil management is not available and also data on residue management is lacking.

Other categories

A comprehensive menu for the entry of “other” emission sources is available, that requires or allows calculation of emission from energy, natural elements and land use change, buildings and materials, organic matter flows, secondary inputs, machinery, and cooling, refrigerant and air conditioning systems.

The **Energy** menu requires data on fuel use and electricity consumption, which is not available. The tool allows further detail, by including several other energy sources and energy uses. Data for this is hugely incomplete.

LC-Farm allows the consideration of the area of several types of linear and patch **natural elements**. This category is not compulsory for final calculations. Many of these are registered in parcel registration data at the level of the Netherlands, while European-scale data is likely available in the near future. Land use changes over the past 20 years, considering 3 main categories, can be entered. While such data can be derived from multiple NL-specific or European spatially explicit datasets, 20-year time series of farm perimeters are not available.

Buildings specific to livestock herds or crop production systems can be specified and quantities of **materials** used in the farm business is included in the tool. No data are available on this. The same applies for **secondary materials,** such as bags, boxes, strings, and lubricants. Data on **machinery** and **cooling, refrigerant and air conditioning systems** is also not available. These data are not compulsory. Finally, the tool allows calculating emissions from **organic matter exchange with other farms.** While the mandatory manure administration does include the amount of manure that is transported off the farm, more detailed insight on end use and transport distance is not available.

Altogether, use of the LC-Farm tool based on existing, top-down data is subject to considerable data gaps. The tool requires a high level of detail on food and feed practices that is not available. Manure data required shows a reasonable match with the mandatory manure administration of the Netherlands, but even under these data-rich conditions the thematic gaps were so large that calculations could not be performed. Many details on livestock herd composition, that would benefit accuracy of calculation, are not available. Although the basic data on crop production required by the tool are available in multiple databases, some essential data are currently of poor quality. The LC-Farm tool utilizes data on irrigation and soil conservation practices that do not match data availability and the same applies to residue management. Data on energy, buildings, materials, cooling are not available. The inclusion of natural elements and land use change lacks flexibility. Although data are partly available, the specific format required by the tool limits the actual use of existing data. The tool checks for consistency across categories (e.g. if pigs are entered, also food has to be entered). When using the tool for a single farm with complete data, this strongly enhances the robustness of the tool. Upon filling LC-Farm with top-down data, the cross-check makes calculation of a partial GHG balances impossible. As a consequence, farm level accounts could not be calculated.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
1	General survey data	Annual work units	FADN	FADN SE425D	
2	General survey data	Agricultural area	FADN / farm perimeter	FADN B48	
3	General survey data	Practices: choice between conventional / organic / conservation / integrated	FADN has data on conventional and organic. Other classes can just be disregarded	FADN A32	
4	General survey data	Nitrate Vulnerable zones: all or part of farm; not affected	Can be checked based on a visual overlay of farm perimeter and JRC / other NVZ map	https://water.jrc.ec.europa.eu/arcgis/apps/webappviewer/index.html?id=efab8e6ac9a840a086b63eed76094b3b	
5	Main products	A prioritization of the main products produced at the farm needs to be made.	FADN allows different ways of prioritization, e.g. based on share of the income generated by a certain end product.		Prioritization requires some basic understanding of the functioning of the farm.
6	Pedoclimatic conditions	Climate zone: Selection from 12 main climate regimes		http://koeppen-geiger.vu-wien.ac.at/present.htm	

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
7	Pedoclimatic conditions	Mineral dominant soil: selection from main FAO soil types	Soil map, e.g. ESDB or StiBoKa	https://esdac.jrc.ec.europa.eu/ESDB_Archive/ESDB/ESDB_Data/ESDB_v2_data_smu_1k.html	Given that FAO Level 1 classes are required, the FAO ESDB map is more convenient and to-the-point than a Dutch map that would have more spatial detail, but on the wrong topic.
8	Pedoclimatic conditions	Dominant soil pH	JRC soil data from MARS; 1km resolution, overlayed with farm perimeter/ location	https://ec.europa.eu/jrc/en/mars	
9	Pedoclimatic conditions	Altitude	DEM combined with farm perimeter/ location	https://ec.europa.eu/jrc/en/mars	
10	Pedoclimatic conditions	Annual rainfall	JRC MARS monthly precipitation data, summed, combined with farm perimeter/ location	https://ec.europa.eu/jrc/en/mars	
11	Pedoclimatic conditions	Rainfall during winter (October-march)	JRC MARS monthly precipitation data, summed, combined with farm perimeter / location	https://ec.europa.eu/jrc/en/mars	
12	Pedoclimatic conditions	Rainfall during summer (april-september)	JRC MARS monthly precipitation data, summed, combined with farm perimeter / location	https://ec.europa.eu/jrc/en/mars	
13	Pedoclimatic conditions	Annual mean temperature	JRC MARS data	https://ec.europa.eu/jrc/en/mars	
14	Pedoclimatic conditions	Mean spring temperature	Can be approximated from JRC MARS data	https://ec.europa.eu/jrc/en/mars	
15	Livestock	Number of dairy cattle, subdivided into 4 weight classes for dairy cows; heifers in 3 age classes, young calves, bulls; at the start and end of the year	FADN; FSS; obligatory farm level administration NL	FADN; variables D22-D49	
16	Livestock	Average weight of categories of dairy cattle	No data.		LC-farm tool is parameterized with average figures

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
17	Livestock	Number of days / year that dairy herd is kept on the farm, subdivided into the same 9 classes	Obligatory farm level administration NL		
17	Livestock	Percentage of time livestock is grazing, subdivided into the same 9 classes	Obligatory farm level administration NL		FADN only provides a basic indicator if livestock grazing is applied.
18	Livestock	Number of dairy cattle sold and purchased, subdivided into the same 9 classes	Obligatory farm level administration NL		
19	Livestock	Overall annual milk production	FADN; obligatory farm level administration NL	FADN SE125	
20	Livestock	Fat content of milk	No data		Average figures available from dairy cooperatives and FSS
21	Livestock	Protein content of milk	No data		Average figures available from dairy cooperatives and FSS
22	Livestock	Quantity of milk powder purchased for calves annually	No data		Quantity of feed purchased is among obligatory farm level administration NL, but no distinction of feedstuff for calves is required
23	Livestock	Type of forage: 19 classes of silage, grasslands, forage products including e.g. hay from natural grasslands / Lucerne; beet feed, grass or maize silage, grazing	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
24	Livestock	Quantity of each type of forage produced and consumed on the farm, tonnes dm/year	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		FADN includes quantities produced for part of the forage types. Data are hugely incomplete, even for the forage that should be reported. Distinction between silage and grazing cannot be made.
25	Livestock	Quantity of each type of forage purchased, tonnes dm/year	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		FADN only includes an overall figure on forage and feedstock spending.
26	Livestock	Overall indication of digestibility of the diet; 10 classes that broadly indicate the forage mix	No data		But can be approximated based on common knowledge
27	Livestock	Quantity of simple feedstuff intake; distinguishing purchased and self produced. Dropdown list with 19 feedstuffs; possible to select the 5 dominant (tonnes fresh matter / year)	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		Impossible to distinguish between beef and dairy cattle.
28	Livestock	Quantity of composed feedstuff intake (tonnes fresh matter / year). Dropdown list with 15 categories, possible to select 5.	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		
29	Livestock	Quantity of own mix of feedstuffs purchased (tonnes fresh matter per year). 3 broad classes: cereals, proteins, energy feed	Part of obligatory farm level administration NL, but thematic detail does not match tool requirements		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
30	Livestock	Manure management systems: possible to select 6 systems from a 18-item dropdown list. For each system, the percentage of total manure dry matter that originates from this particular system is to be entered.	Part of obligatory farm level administration NL, at a lower level of detail.		Some Dutch provinces collect some additional data, for licensing purposes.
31	Livestock	Data on dairy goat and sheep	FADN, FSS		Data requirements are similar to dairy cattle
32	Livestock	Data on beef, meat sheep, other ruminants kept for meat, pig, poultry and other kept for meat	FADN, FSS		Data requirements are similar to dairy cattle, except that no data on specific outputs (quantities of meat) are required.
33	Livestock	Data on laying hens	FADN, FSS		Data requirements are similar to dairy cattle. Annual egg production is required.
34	Crop production	Crop type: selection from >100 crop types	FADN, FSS, obligatory farm level administration NL; parcel databases NL		Limitations include that not all datasets distinguish grassland types. Shortly forthcoming sentinel based dataset provide potential here.
35	Crop production	Fertiliser purchases (euros/year)	FADN		
36	Crop production	Annual cost of pesticides (euros / year)	FADN		
	Crop production	For each crop, items 35-39 are mandatory			
35	Crop production	Crop area (ha)	FADN, FSS, obligatory farm level administration NL; parcel databases NL		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
36	Crop production	Yield (ton dry matter)	FADN, FSS, obligatory farm level administration NL	Atlas Natural Capital, SAPM, parcel map,	Databases are not consistent in providing dry vs fresh matter, which can result in data gaps or inconsistencies among farms. In the Netherlands, maps of potential yield and yield gap are available through Atlas Natural Capital. These can be coupled to parcel information. A similar calculation can be done on European scale with e.g. SAPM maps, which, however, have a coarse spatial resolution
37	Crop production	Production on organic soils yes / no	Parcel databases NL combined with map of organic soils and farm perimeter data	Soil map NL / ESDB	Data on organic soils in the Netherlands is obsolete. New data are emerging, e.g. based on upscaling LUCAS data.
38	Crop production	Use of organic manure yes / no	Obligatory farm level administration NL; though not at the crop level.		
39	Crop production	Use of machinery for soil tillage, seeding / planting, manure spreading, pesticide treatments, forage / hay harvest, residues and co-products harvest, self-propelled machinery for crop harvest; number of operations and fuel consumption per operation	No data		The tool is parameterized with average figures on fuel use per operation. Data on forage / hay harvest frequency is emerging from sentinel. Seeding / planting frequency can, in the near future, be derived from sentinel crop rotation maps but is for a single crop very likely to be one.
40	Crop production	For each crop, items 41-yyy are optional			

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
41	Crop production	Mineral fertilizers applied on crop, kg NPK/ha, subdivided into 10 types of fertilizer and 5 elements	No data (only manure is part of mandatory reporting)		
42	Crop production	Type and quantity of liquid and solid manure per year; ton/ha	Is included in mandatory reporting; only overall farm level figures		strict maximum figures in the NL which are more or less treated as the norm.
43	Crop production	Abatement technique for manure and slurry spreading (dropdown menu with 7 + 7 items)	No data		
44	Crop production	Number of treatments of the crop with herbicides, fungicides, insecticides, other	NL National Statistics surveys every 4 years. No compulsory reporting.		
45	Crop production	Management of crop residues: burnt, removed, incorporated	No data		
46	Crop production	Quality of burnt residues	No data		
47	Crop production	Tillage operations: No / reduced / full tillage	No data		Except if the specific field has a LUCAS observation point.
48	Crop production	% legumes in the crop	No data		
49	Crop production	Quantity of purchased seeds (kg/ha)	No data		
50	Crop production	In vineyards or orchards: surface of grass under main crop (ha)	No data		This might be very challenging for satellite derived data. Probably, no scope for future consideration
51	Crop production	In agroforestry: # trees per hectare	No data		
52	Crop production	Indication if the land is covered during winter	Depending on the crop, this could be derived from parcel registration data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
53	Crop production	Indication if residues from cover crops are incorporated	No data		
54	Crop production	Indication if the land is grazed by animals	No data; only available at farm level and not per crop.		FADN stocking density figures could provide potential for approximations
55	Crop production	Indication if the soils are drained	No data		Except if the specific field has a LUCAS observation point. Also, the presence of ditches in the direct vicinity can provide an approximation
56	Crop production	Share of the production of the crop of the farm final products in %	No data		
57	Crop production	For grassland: indication if the land is overgrazed	No data		
58	Crop production	For grassland: indication if there are long-term productivity losses	No data		Could in the near future be approximated based on sentinel data
59	Crop production	Grassland: indication if productive grass varieties or legumes were seeded in recent years	No data		
60	Crop production	Irrigated surface (ha)	FADN		
61	Crop production	Total volume of irrigation water used	No data		FSS might provide data, although no proper time series
62	Crop production	Type of energy used for irrigation (electricity, fuel, gravity)	No data		Except if the specific field has a LUCAS observation point.
63	Crop production	Type of irrigation (individual / collective)	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
64	Crop production	For collective irrigation: operating pressure level (high-medium-low)	No data		
	Other inputs – energy: compulsory data				
65	Other inputs – energy	Consumption of liquid fossil fuel by tractors and machinery (l)	No data		
66	Other inputs – energy	Annual electricity consumption for all uses except irrigation (kWh)	No data		
	Other inputs – energy: optional data				
67	Other inputs – energy	Consumption of liquid fossil fuel for heating, pumping, other uses, and cars and trucks (l)	No data		
68	Other inputs – energy	Fuel consumption for and by third parties (l)	No data		
69	Other inputs – energy	Consumption of petrol, propane or butane, natural gas, and coal (l / kg / m3)	No data		
70	Other inputs – energy	Attribution of fuel consumption to 5 main products (%)	No data		
71	Other uses – energy	Attribution of electricity consumption to 5 main farm products (%)	No data		
72	Other uses – energy	Attribution of water consumption to 5 main farm products (%)	No data		
73	Other uses – energy	Electricity use for individual irrigation pumping system (kWh)	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
74	Other uses – water	Annual consumption of drinking water (m3)	No data		
75	Other uses – energy	Annual cost of electricity	FADN		
76	Other uses – water	Annual cost of drinking water	FADN?		
77	Other uses – water	Annual cost of irrigation water from collective pumping system (low-medium-high pressure level	No data		
78	Other uses – energy	Quantity of consumed renewable energy products	No data		Also uses the substituted energy sources. 9 different renewable energy sources are included in the tool
79	Other uses – energy	Quantity of sold renewable energy products	No data		
80	Other uses – energy	Potential for renewable energy: heating needs, hot water needs, roof surface facing south	No data		
	Other uses – Natural elements				All entries in this category are optional
81	Other uses – Natural elements	Length, width and overall quality of woody natural elements (space for 4 items, dropdown menu with 7 types)	NL Parcel maps matches 4 of the 7 types of woody natural elements.	Nationaalgeoregister.nl: basisregistratie gewaspercelen	Only provides areas, but conversion into length/width is obviously straightforward. Quality data is not available. Sentinel might provide potential in the near future.
82	Other uses – Natural elements	Length, width and overall quality shrubby natural elements (space for 4 items, dropdown menu with 3 types)	NL parcel maps matches 1 of the types. Heathlands can be extracted from land cover map.	Nationaalgeoregister.nl: basisregistratie gewaspercelen	
83	Other uses – Natural elements	Vineyards and orchards (hectares)	Multiple data sources, including farm land use statistics and parcel maps	Nationaalgeoregister.nl: basisregistratie gewaspercelen	

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
84	Other uses – Natural elements	Width, length, and quality of low natural elements (space for 4 items, dropdown menu with 8 types)	NL parcel maps match 3 of 8 types of low natural elements.	Nationaalgeoregister.nl: basisregistratie gewaspercelen	
85	Other uses – natural elements	Hectares converted between cropland, grassland, and forest over the past 20 years, at farm scale.	Time series of land cover data are available; sufficient time series of farm perimeters probably not.	Corine land cover	
	Other uses – buildings and materials				All entries in this category are optional
86	Other uses – buildings and materials	10 buildings linked to specific products or livestock herds can be entered. 34 types of buildings are parameterized. Age and surface has to be specified	No data. Only the area of greenhouse / glasshouse can be derived, from FADN or land cover data.		
87	Other uses – buildings and materials	10 general buildings can be entered, 8 types are parameterized. Age and surface has to be specified and buildings have to be attributed to the 5 main products	No data		
88	Other uses- buildings and materials	Materials utilized at farm, such as concrete, steel, plastics, glass. The age and quantity has to be entered and materials should be attributed to the 5 main farm products	No data		
89	Other uses - secondary	Quantities of bags, plastic, strings, cardboard, hoses, glass, and lubricants. Attributed to 5 main farm products.			Optional data
	Other uses – machinery				All entries in this category are optional

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
90	Other uses – machinery	Broad indication, hp, age, % use on farm, attribution to 5 main farm products of tractors	No data		
91	Other uses – machinery	Broad indication, hp, age, % use on farm, attribution to 5 main farm products of transportation vehicles	No data		
92	Other uses - machinery	Soil tillage equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
93	Other uses – machinery	Seeding and planting equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
94	Other uses – machinery	Manure spreading equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
95	Other uses – machinery	Treatment equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
96	Other uses – machinery	Forage / hay harvest equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
97	Other uses - machinery	Mineral fertilization spreading equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
98	Other uses – machinery	Crop harvest equipment: 5 machines can be entered. Age and % use on farm needed.	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
99	Other uses – machinery	Residues harvest equipment: 5 machines can be entered. Age and % use on farm needed.	No data		
100	Other uses – machinery	Livestock equipment: 5 things; age and % of use on farm as well as distribution over 5 main farm products	No data		
101	Other uses - machinery	Other equipment: 5 things; age and % of use on farm as well as distribution over 5 main farm products	No data		
102	Other uses – cooling	Volume and cooling agent used for milk tank; quantity of gas and frequency of renewal	No data		
103	Other uses – cooling	Air conditioning in tractors, self-propelled machinery and cars; number of machines equipped, type of fluid, quantity of gas, frequency of renewal.	No data		
104	Other uses – cooling	Capacity and type of cooling fluid for 8 different industrial cooling systems	No data		
105	Other uses – cooling	Retail refrigeration used on the farm for direct sale; power and type of fluid. 10 different systems / situations	No data		
106	Other uses – cooling	Cooling capacity and type of fluid for cooling for 4 different means of refrigerated product transport	No data		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
107	Other uses – cooling	Cooling capacity and type of fluid used for water – cooled or air-cooled air conditioning in offices	No data		
108	Organic matter flows	Amount and type of organic matter that is exchanged with other farms, including type of transport, end use, and transport distance	Amounts of manure exchanged are in the mandatory administration for each type of manure. Other data are not available.		

Annex 3: Evaluation of EX-ACT tool inputs

Baseline information

Information on a main soil type is required. As only one soil type can be chosen, this will, in many cases, introduce a considerable uncertainty, although the soil classification is so broad that this is deemed acceptable. For application of the tool on larger areas or projects, sub assessments for different intersections of regions and main soil types need to be made.

Land use change

The Land use change category requires gross land use changes, that can be taken from a reclassified version of Corine Land Cover (See Table 4). The match between the classes available in the tool and the dominant land use changes in the EU territory is a main limitation. EX-ACT requires data on degraded land, that cannot, with any certainty, be derived from existing spatial data. Tier 2 calculations require data on carbon stocks in above-ground and below-ground vegetation, litter, dead wood, soil carbon. For assessing afforestation, Tier 2 data should include above- and below-ground growth rates for forests up to 20 years old and over 20 years old. For other land use changes, soil carbon and biomass data are needed for the Tier 2 assessment. While soil carbon data are available originating from LUCAS inventories, other are not available as wall-to-wall data, limiting the possibility of a Tier 2 assessment. Currently, only one-time slice of LUCAS soil organic carbon data is available, meaning that also for soil organic carbon, currently, no Tier 2 assessment can be performed.

Crop production

The Crop production module first requires data on crop areas and yields. These are available through annual inventories from Eurostat. These indicators face considerable datasets, with lack of data on permanent crops and incomplete data for Germany and some eastern European countries. For the assessments of effects of conversions from and to cropland on greenhouse gas emissions, the tool is limited to the evaluation of just one crop type. For cropland remaining cropland, 10 main crops and flooded rice as an additional category can be selected. As spatially explicit land cover data is often not consistent with crop statistics, we ensured consistency in areas between the land use change module and the crop production module by converting the areas of different crops derived from Eurostat into percentages and distributing these over the cropland areas as identified from Corine Land Cover in the land use change module. Forthcoming Sentinel products that are able to combine spatially explicit land cover data with crop cover will allow overcoming this procedure.

For cropland management, only very general data are needed. The tool utilizes the presence or absence of improved agronomic practices, nutrient management, no-till and residue retention, water management, and manure application for the calculation of greenhouse gas accounts.

No-till, nutrient retention and water management can be derived from LUCAS data; manure application is recorded in FADN statistics and can be aggregated to NUTS2 level. The tool however also requires details on the management of flooded rice, which are not available.

A Tier 2 assessment of crop production related emission requires rates of soil carbon sequestration and the quantity of biomass residues available. The Tier 2 assessment also allows for evaluation of a minor season crop or intercropping and allows for more detail on residue management. Data for the more detailed assessment of residue management are not available, while a broad indication of the minor season crop and intercropping can be derived from LUCAS data, although the classification of LUCAS does not fit the classification required by EX-ACT.

Grassland, livestock

EX-ACT has a joint calculation module for grassland and livestock emission and sequestration. EX-ACT enables distinguishing three classes of grassland degradation (undegraded, moderately degraded, severely degraded) as well as improved grassland without or with inputs. This classification of grassland degradation is not compatible with any existing spatially explicit data. Data on grassland improvements are not available. The best approximation could be made by assuming that grassland is improved in NUTS2 regions or countries where fertilization is applied, although this cannot be attributed with certainty to grasslands. Forthcoming Sentinel derived products that also would allow detailed tracking of temporal changes are unlikely to meet these data requirements either. Next, the use of fire for grassland management needs to be included. Fire occurrence can be derived at moderate to high resolution from MODIS, but EX-ACT requires attribution of fire to deliberate fire management. This is not possible in a reliable way. For grassland yield, data are available in FSS and annual crop statistics, although both data source demonstrate considerable data gaps.

Livestock numbers are available at mostly NUTS2 level. A limited number of data gaps can be filled up with country level data, resulting in the introduction of minor uncertainties. Milk production figures are available at NUTS2. EX-ACT also requires statistics on meat production. These are only available at country level, with poultry meat data are completely lacking. Two reasonable options for downscaling to NUTS2 include first a downscaling from country level based on NUTS2 level livestock numbers derived from the FSS, or second based on earnings from meat. These data would need to be aggregated from farm level to NUTS2 level using FADN data.

A Tier 2 level of grassland and livestock emissions analysis requires data on soil carbon stocks. While these are available (see section on crop production above), it is not possible to distinguish between different degradation and improvement levels. Data on above-ground carbon stocks and on combustion percentages are not available, limiting the added value of a Tier 2 analysis.

Forest management and degradation

The forest management and land degradation category requires the indication of the degradation level of forested land. Six levels are available (none – very low – low – moderate – high – extreme). While this could be approximated based on harvest intensities, e.g. based on the 1-km-resolution map from Verkerk et al. (2015)[146], no time series are available and the translation of harvest intensities into degradation levels based on expert judgement is likely to introduce additional uncertainties. National-scale figures on harvest are available through Eurostat. These lack the required spatial resolution and suffer from the same uncertainties as the aforementioned map.

A second issue addressed in this category are greenhouse gas emissions from drainage and rewetting of organic soils. While the presence of drainage can be derived from LUCAS, data on rewetting is absent. An overlay of drainage data from LUCAS with the presence / absence of organic soils is highly uncertain, due to the low number of observations in peat areas.

Third, EX-ACT considers peat extraction. While the JRC soil data centre does have spatially explicit data on the resources, this cannot be translated into peat extraction activities. The effects of fire related emissions can, just as for grassland, be derived from MODIS data, but attribution to wildfires and prescribed fires is not possible.

The Tier 2 analysis for forest management and degradation requires case specific emission factors for CO_2, CH_4 and N_2O, from drained soils and ditches. This applies to all the categories of degradation related emissions. Altogether, a Tier 2 analysis for this category is out of scope due to lack of data.

Coastal wetlands

The Coastal wetlands category estimates emissions from extraction and excavation, drainage, and rewetting of mangroves, tidal marshes, and seagrass meadows. Consideration of this category is hampered by the lack of data on vegetation changes other than tidal marshes. These vegetation types are, however, of limited relevance for the European territory. Spatially explicit data on rewetting is not available, but experimental EO based soil water products might provide the potential to map rewetting of coastal wetlands in the near future.

A Tier 2 analysis requires data on carbon pools, in above- and belowground vegetation, litter, and dead wood, as well as percentage of C lost after the management intervention. These data are not available, neither for single time slices nor as time series.

Inputs and investments

The Inputs and investments category considers emissions from lime, fertilizer, and pesticide application in agriculture, as well as energy consumption and the construction of new infrastructure. There are many data gaps in this category. Data on lime and Kalium is not available, while data on phosphorus and nitrogen is aggregated to country level and only collected at the level of nutrients. Energy data are, generally, only registered at country level and the thematic detail of the tool (distinguishing 10 types of fuel) cannot be matched by statistical data.

[146] Verkerk, et al. 2015: Mapping wood production in European forests, Forest Ecology And Management 357: 228-238

Infrastructure changes have to be recorded for several topics. Changes in irrigation infrastructure can, at NUTS2 level, be derived from LUCAS inventories, although the thematic detail of the tool is considerably higher than the thematic detail of the LUCAS irrigation inventory efforts and LUCAS has a revisit time of 3 years. The category also allows for a better specification of the expansion of built areas. However, the infrastructure changes calculation only considers the construction related emissions, while the emissions related to the underlying land use changes should be approximated in the land use change category.

A Tier 2 analysis requires country specific emission factors and provides the possibility to specify emissions from storage and transport For energy use, Tier 2 analysis can be used to specify country specific CO_2 emissions per unit fuel use and the same applies for the construction of new infrastructure.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
1	Description	Continent	Drop-down list with 11 subcontinents.	n/a	n/a
2	Description	Climate	Drop-down list with 5 main climates.	n/a	For using the tool at NUTS2 level, in most cases the 5 categories provide sufficient detail.
3.	Description	Moisture regime	Drop-down list with 3 main moisture regimes	n/a	For using the tool at NUTS2 level, in most cases the 3 categories provide sufficient detail.
4.	Description	Dominant regional soil type	Drop-down list with 6 main soil types.	Checked against the JRC ESDAC soil map.	Using one main soil type per NUTS2 region is too coarse. Several NUTS2 regions harbor soils with different functionality, meaning that for proper use of the tool, an intersection between NUTS2 regions and soil types needs to be made and used as a basis.
5.	Description	Duration of the project: Implementation phase, capitalization phase, duration of accounting	This is proxied by the difference in reference year of the most recent CORINE land cover maps.	n/a	n/a

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
6.	LUC	Deforestation: type of vegetation	For this climatic zone, a distinction can be made between temperate oceanic and continental forest, and temperate mountain forest.	Corine Land Cover 2009 2012, reclassified into forests.	At NUTS2 resolution, this is a sufficient level of detail. 8 combinations of forest type and land use after deforestation can be included. The tool provides 8 possible land uses after deforestation. In most cases this will be sufficient; otherwise a prioritization based on area should be made.
7.	LUC	Final use after deforestation	A distinction can be made between annuals, perennials, grassland, flooded rice, set aside, degraded, other (nominal / degraded).	Corine Land Cover 2009 and 2012, reclassified to distinguish only the main classes	
8.	LUC	Harvested wood products (ton DM/ha)	Taken from a 0.1 degree wood harvest map, averaged to NUTS2 level. Alternative data is country level statistics on wood harvest from Eurostat (for_remov)	Verkerk (201x) (VOLANTE); Eurostat.	The more detailed Verkerk map is a one-time effort, with 2010 as a reference year. It does suggest considerable variation within NUTS regions, but doesn't account for temporal variability. The Eurostat data suggests considerable inter-year variation, but doesn't have sufficient spatial detail.
9.	LUC	Fire use yes/no	In this case approximated based on general knowledge. Generally, it can be derived from MODIS burnt areas data. These are summarized for the time period considered and overlayed with forest data	Giglio, L., Justice, C., Boschetti, L., Roy, D. (2015). *MCD64A1 MODIS/Terra+Aqua Burned Area Monthly L3 Global 500m SIN Grid V006* [Data set]. NASA EOSDIS Land Processes DAAC. doi: 10.5067/MODIS/MCD64A1.006	MODIS does only indicate if area has been burnt, not if it was a management strategy or not.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
10.	LUC	Deforested area (ha)	This requires gross changes. Derived from a reclassified version of Corine land cover.	CLC 2009 and 2012.	The land cover classification is very broad and doesn't account for one of the main land use changes: urbanization. This has to be included as degraded land. A maximum number of land use conversions can be assessed. All changes from and towards forest can be included in the deforestation and afforestation categories, meaning that 5^2=25 conversions would be possible for the other land use changes category. This only allows for the 10 types of conversions. While limiting to the 10 dominant conversions is the most suitable option, this does introduce uncertainties.
11.	LUC	Afforested area	Idem	Idem	Idem
12.	LUC	Other land use changes	Idem	Idem	Idem
13.	Crop production	Annual crop systems facing changes	A main season crop has to be chosen. For a NUTS2 region, in many cases there would be several rather than one dominant.	FSS, Corine Land Cover	
14.	Crop production	Annual systems remaining	Here, 10 different crops can be included, from a drop-down list with 10 options.	FSS, Corine Land Cover	
15.	Crop production	Improved agronomic practices yes/no	Data on this (improved varieties, extending crop rotation, increasing residues) is not available.		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
16.	Crop production	Nutrient management yes/no	Data on implementation of practices to improve N use efficiency and decrease N losses is not available. It can be approximated on a "yes/no basis" using different data sources with different levels of detail.	Potter, P., N. Ramankutty, E.M. Bennett, and S.D. Donner. 2011. Global Fertilizer and Manure, Version 1: Nitrogen Fertilizer Application. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4Q81B0R. Accessed 11 06 2018. Eurostat, aei_pr_gnb	Potter et al. provides a 0.5 degree resolution map, however based on downscaled statistical data. Eurostat provides country level statistics, including gross and net nitrogen balances. A small but positive nitrogen balance can be assumed a proxy for improved nitrogen balances.
17.	Crop production	No till and residue retention yes/no	Data on the adoption of no till and conservation agriculture are available at NUTS2 level in 2010 from Eurostat.	Eurostat, ef_pmtilaa	
18.	Crop production	Water management yes / no	Data on the uptake of efficient irrigation measures at NUTS2 level is available from Eurostat for 2010.	Eurostat, ef_poirrig	
19.	Crop production	Manure application yes / no	Data on manure input is available from different data sources.	Eurostat, aei_pr_gnb; Potter et al. 2010	
20.	Crop production	Residue management burned / exported	No data available. Burned can be ruled out using the fire map	MODIS	But it cannot be certified if burning is used as a management tool.
21.	Crop production	Yield (Ton/ha per year)	Average data can be derived from various data sources, that are, however, all surprisingly incomplete, particularly for perennials.	FADN, Eurostat apro_cpshr	The tool provides the possibility to specify different yield levels for continuous crops and changed / changing crops. This is not necessary and not feasible. For all 10 crops, data are available at country level or more detailed.
22.	Crop production	Flooded rice: cultivation period (days)	No data available		Possible derivable from MODIS or Sentinel-2 data, currently not available.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
23.	Crop production	Flooded rice: water regime during cultivation period	Drop-down menu containing continuously or intermittently flooded, and rainfed and deep water. Rainfed vs irrigated is available; intermittently or not will be possible to derive from Sentinel time series, but not for now.	Siebert and Doll (2007)	
24.	Crop production	Flooded rice: water regime before cultivation period	Drop-down menu containing non flooded preseason < and > 180 days, and flooded preseason >30 days. It will be possible to derive this from Sentinel time series, but not for now		
25.	Crop production	Flooded rice: organic amendment type	Drop-down menu containing straw burned or exported, straw incorporated < or > 30 days before cultivation, compost, farmyard manure, green manure. Data on this are not available from any known dataset.		
26.	Crop production	Flooded rice: yields (ton / ha per year)	Data available from Eurostat, largely just at country level.	Eurostat, apro_cpshr	
27.	Grassland livestock	Initial state, final state with / without project	Drop-down menu containing non-moderately-severely degraded, improved without / with inputs. This does not match any available input data.		
28.	Grassland livestock	Fire use to manage yes/no; periodicity	Can be derived from Modis	MODIS	But it cannot be certified if burning is used as a management tool.
29.	Grassland livestock	Yield (ton / ha)	Time series available from Eurostat	Eurostat, apro_cpshr	Hugely incomplete and largely only at country level.
30.	Grassland livestock	Heads per year, 9 species	Time series available from Eurostat	Eurostat fss, ef_olsaareg	

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
31.	Grassland livestock	Technical mitigation options, %	Neither on feeding practices, specific agents, and breeding are data available.		FADN does only contain total spendings on the aggregated set of technical mitigation options. There is no possibility for disaggregation.
32.	Grassland livestock	Production, tonnes / year	Data on milk at NUTS2, data on meat at country level downscaled to NUTS2.	Eurostat, agr_r_milkpr Eurostat, apro_mt_pann downscaled using ef_olsaareg	Downscaling based on livestock numbers might introduce uncertainties due to weight differences among provinces. Alternatively, downscaling based on earnings is sensitive to price volatility.
33.	Forest degradation and management	Degradation level of the vegetation, 6 classes related to a % of degraded area	This can be used to include the impact of harvest on forest carbon stocks. Based on Levers et al. (2014), the degradation level can be set at 0% for intensities <75%, 10% for 75%-100%, 20% for 100-300%, 40% for 300-500%, and 60% for >500%.	Levers, C., et al. (2014). "Drivers of forest harvesting intensity patterns in Europe." Forest Ecology and Management **315**(C): 160-172.	The map by Levers et al. is a one-time effort, hence, no changes in harvest intensity can be simulated.
34.	Forest degradation and management	Fire use to manage yes/no; periodicity	Can be derived from Modis	MODIS	But it cannot be certified if burning is used as a management tool.
35.	Forest degradation and management	Areas (ha)	Several good-quality data sources available, see land use change module.	See land use change.	See land use change.
36.	Forest degradation and management	Surface of drained organic soils (ha) by type of vegetation	It can safely be assumed that all managed land on organic soils is drained. By overlaying the land use map with a soil map, the drained organic soils can be derived and areas can be calculated.	ESDAC soil maps; LUCAS SOC map; …	Although the assumption of full drainage is reasonable, it is an assumption that cannot be verified easily with high certainty.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
37.	Forest degradation and management	Percentage area of ditches	Van der Zanden et al. (2014) ditches map quantifies the probability that a ditch is encountered on a 250m transect. Each 1km^2 gridcell with an >50% probability can be considered drained.	Van der Zanden, E. H., et al. (2013). "Modelling the spatial distribution of linear landscape elements in Europe." Ecological Indicators **27**: 125-136.	Although the map is a one-time effort, the methodology can be repeated on new LUCAS data, resulting in a 3-year temporal resolution.
38.	Forest degradation and management	Active peat extraction, surface area where extracted and height of extraction; quantity of peat produced in ton/yr.	The closed proxy is Eurostat data on energy derived from peat at country level. This can be translated into volumes of peat using average energy content and bulk density data. If these volumes are put to areas on peat soils not under a specific use or under mining, one can, with using a standard depth, get an idea of the area needed.	Eurostat, nrg_109a ESDAC soil maps,	This calculation is in theory feasible. In practice, it requires many uncertain steps, making it not worth the effort because of considerable uncertainty propagation.
39.	Forest degradation and management	Surface of rewetted organic soils (ha)	No data available. Might, in the future, be derived from Sentinel data combined with soil data.	ESDAC soil maps, sentinel [specify]	
40.	Forest degradation and management	Area burnt (ha), classified into wildfire on drained and undrained peat, and prescribed fire	MODIS fire data can be combined with ditches occurrence.	MODIS, Van der Zanden, E. H., et al. (2013). "Modelling the spatial distribution of linear landscape elements in Europe." Ecological Indicators **27**: 125-136.	Distinction between prescribed and non prescribed fire is not possible.
41.	Coastal wetlands	Area (ha) and % excavated, for mangrove, tidal marsh, seagrass meadow.	Corine land cover includes tidal marsh, meaning that changes can be included. The EEA ecosystem map contains seagrass meadows.	CLC, European Commision Technical report – 2016 – 095; Mapping and Assessment of Ecosystems and their Services — Mapping and assessing the condition of Europe's ecosystems: progress and challenges — 3rd Report – Final, March 2016.	Mangroves do not apply in Europe. The EEA map was a one-time effort.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
42.	Coastal wetlands	Area % drained	Can be mapped by overlaying the maps from (41) with a ditch density map	MODIS, Van der Zanden, E. H., et al. (2013). "Modelling the spatial distribution of linear landscape elements in Europe." Ecological Indicators **27**: 125-136.	
43.	Coastal wetlands	Area rewetted (ha)	No data available.		Might, in the future, be derived from Sentinel data
44.	Inputs Investments	Lime application (tonnes per year; limestone / dolomite / ns)	No data available.		
45.	Inputs Investments	Fertilizers (tonnes per year; urea, other N, N in irrigated rice, sewage, compost, P_2O_5, K_2O)	Data are available for unspecified N fertilizers and for P_2O_5 in the right units, at country level. Downscaling using the UAA would be possible.	Eurostat, aei_fm_usefert + UAA data, best from ef_lus_main for the sake of consistency.	Downscaling based on UAA is the most reliable option, but disregards intensity variation within a country. The use of static intensity maps, e.g. from VOLANTE, would be an option, but introduces an other uncertainty step.
46.	Inputs Investments	Pesticides (tonnes of active ingredient per year; herbicides, insecticides and fungicides).	Sales in kilogram active ingredients are available at country level. Similar to fertilizers, these can be downscaled to smaller areas using the UAA.	Eurostat, aei_fm_salpest09 + UAA data, best from ef_lus_main for the sake of consistency.	Downscaling based on UAA is the most reliable option, but disregards intensity variation within a country. One has to assume that all the sales are actually applied, which is, on the longer term, a reasonable assumption.
47.	Inputs Investments	Electricity use (MWh / year)	Energy use per sector is available at country level. Downscaling would be possible based on the sector sizes in different NUTS2 regions. Data are in Terajoule, which can be translated into MWh.	Eurostat, env_ac_pefasu	Downscaling disregards efficiency differences (and efficiency improvements) among NUTS2 regions.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
48.	Inputs Investments	Fuel use: diesel, gasoline, gas, butane, propane, ethanol, other in m^3 per year; wood, peat in tonnes dm per year	Energy use per sector at country level does contain data on many of these fuels. Translation of Terajoules into the weights or volumes required by the tools is possible using standard energy densities.	Eurostat, env_ac_pefasu; https://en.wikipedia.org/wiki/Energy_density#Energy_densities_of_common_energy_storage_materials	Energy densities are different among countries. Using an average value when calculating weight or volume introduces uncertainties.
49.	Inputs Investments	Irrigation systems (in ha; distinguishing 9 different systems)	Irrigated UAA as a % of total UAA is available at a temporal resolution of a few years. Using UAA data, the area can be calculated.	Eurostat, aei_ef_ir + UAA data, best from ef_lus_main for the sake of consistency	A standard irrigation system has to be assumed, most reliably based on the standard system in the country.
50.	Inputs Investments	Buildings and roads (in m^2)	Areas with new buildings and roads can be derived from land cover data. Current land cover data does not make the distinction between the different types of buildings and roads that can be specified in the tool.	CLC	An arbitrary distribution over a few main categories can be made. If land cover data allows (e.g., in the Netherlands) a few main categories can be quantified based on real data.

Annex 4: Evaluation of SOSTARE inputs

SOSTARE is a tool for calculating a broad sustainability indicator. It builds on 37 indicators that are aggregated into 12 themes: cropping system, fertilizer management, energy management, water management, agrochemicals management, value of production, value added, farm household income, CAP independence, farm business diversification, natural value, functional landscape pattern. Upon aggregating, dimensionless indices of the 12 themes are created that are displayed in a radar plot to allow qualitative analysis of trade-offs.

The tool allows comparison of different management schemes, which can be quantified using the 37 indicators and be jointly visualized. The tool is farm specific.

SOSTARE uses data on crop rotations, legumes, grassland area, tilled area, organic matter, NPK balance at farm gate, fossil energy use, energy efficiency, linear elements. The possibility to navigate trade-offs and communicate them in a clear and easily understandable way is an asset of the tool. Also, the wide range of topics included is an asset. Although not all factors are related to CSA, the factors that are relevant provide a broad coverage of CSA topics and measures.

The tool calculates indices for 7 topics, which can either be presented separately or be aggregated. After an initial exploration of farm carbon tools, SOSTARE was disregarded because (1) it did not provide the possibility to explicitly include greenhouse gas emissions from livestock, and (2) SOSTARE provides an overall, semi-quantitative, index of sustainability, which was deemed inferior to the emission quantities estimated by the other tools. Given the data constraints encountered during the development of databases that could be utilized to feed the other two tools, SOSTARE was reconsidered. The tool was evaluated in the same way as EX-ACT, LC-Farm and FCC, by systematically quantifying the tool output while collecting data, at both farm scale and European scale with a NUTS2 resolution.

Because SOSTARE does not calculate greenhouse gas emissions, we also mapped greenhouse gas emissions from land use, livestock, and energy use in a consistent way. We collected and harmonized data for the calculation of a greenhouse gas account for land use change and livestock. Activity data on these two topics are of reasonable quality, and are not optimally used in the other tools. Together with overall emission factors, these activity data were utilized to get a spatially disaggregated greenhouse gas account.

The following paragraphs provide an inventory of the data needs of the SOSTARE tool and for an EU scale GHG emissions quantification. The described data are added in an excel annex (sheets FarmData, EU_GHG, EU_SOSTARE) and allow comparison of SOSTARE and farm tool-based greenhouse gas quantifications.

For **Cropping system and fertility,** most of the indicators needed for index calculation at NUTS2 scale are available. The tool does require some spatially explicit data to track crop changes within or between years. For a regional scale application, several indicators can be approximated based on LUCAS observations. Tillage practices have been inventoried in a one-time effort survey in 2010 (Survey on Agricultural

Production Methods), but are now surveyed in a general way in LUCAS, with a 3-year interval. These data can be used to calculate a percentage tilled area at NUTS2 level.

At farm level, many of the indicators can be derived from the FADN database. National level detailed crop / land use maps for the Netherlands allow calculation of spatially explicit indicators.

The topic of **nutrient application and management** faces some data gaps. A major gap is that reporting on K balances is limited and that N and P balances are only registered at country resolution. The use of crop residues can be derived from LUCAS for the NUTS2 level analysis, while for a farm level analysis data on green manure can be derived from parcel registration. Both datasets are available in (small) time series, however with a low (1 or 3 year) temporal resolution.

As for the other tools, the availability of data on **energy consumption** is a major limitation. The SOSTARE tool just includes four basic indicators on the consumption of non-renewable energy, that could be approximated based on a downscaling of national, sector specific figures weighted by farm-level energy spending. An approximation of indirect energy use and energy output can be done based on downscaling national data and with the use of Tier 1 energy contents. While this is likely to introduce considerable uncertainties, it enables comparison within countries. However, sector specific energy use is not available for Germany while FADN data on energy spending lacks data for Bulgaria, Czech, Denmark, Hungary, Lithuania, Latvia, Poland, Romania, and the UK.

Some of the data on **water resource management** is available at farm level. This includes the area of irrigated UAA. The LUCAS dataset allows for a regional scale calculation of all the indicators in this category.

Data on **agrochemical management** is lacking completely. As this category is of little relevance for climate smart agriculture, that is not deemed problematic.

The **economic** indicators except for diversification can be easily calculated using FADN data. For a NUTS2 level application, farm level figures can be aggregated. As this is of lower relevance for climate smart agriculture, the category was disregarded.

The SOSTARE **Ecological** indicators are based on input data that are available both at farm level and at NUTS2 level. Only core areas of indigenous vegetation patches cannot be derived from existing data. Some of the indicators are of lesser relevance to climate smart agriculture.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
1	A16 Cropping system and soil fertility	Proportion of UAA that is sown with 2 different crops in two subsequent years	NL parcel registration data; comparison of 2 subsequent years; combined with farm perimeter / location data	FADN SExx; parcel data	For farm level as well as for the assessment of regions, forthcoming sentinel products provide good data.
2	A19 Cropping system and soil fertility	Proportion of UAA that is double cropped over one year	At farm level, no data available. At regional scale, derived from LUCAS (presence of 2nd land cover type at observation point)	LUCAS; LC2	For farm level as well as for the assessment of regions, forthcoming sentinel products provide good data.
3	A20 Cropping system and soil fertility	Proportion of UAA that is sown with a legume crop	Farm level: FADN, summing up the relevant crop areas: K340 + K360. Regional level: LUCAS crops B51-B53	FADN; LUCAS land use	Forthcoming sentinel products might potentially provide data at higher temporal and spatial resolution, but the accurate classification of legumes is still doubtful
4	A21 Cropping system and soil fertility	Proportion of the UAA that is sown with a crop that covers soil during the winter period	FADN, summing up the relevant crops at farm scale: ….. Regional level: LUCAS crops B50-B84	FADN, LUCAS land use	Forthcoming sentinel products might potentially provide data at higher temporal and spatial resolution,
5	A22 Cropping system and soil fertility	Proportion of perennial meadows on the total UAA	Farm level: FADN; NL parcel registration data. Regional level: LUCAS: LU=U111 and LC = E10 or E20	FADN, LUCAS, parcel data NL	Forthcoming sentinel products will provide data at higher temporal and spatial resolution,
6	A91 Cropping system and soil fertility	Proportion of the UAA that was conventionally ploughed	No data at farm level. Regional level: LUCAS observations on ploughing	LUCAS	
7	A92 Cropping system and soil fertility	Proportion of the UAA that was amended with organic manure, crop residue, and/or green manure	Green manure species can be derived from parcel registration data (farm level NL) or LUCAS (regional level). Use of organic manure is in FADN and in mandatory manure administration.		

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
8	Nutrient application and management	A27 Farm-scale balance for N	Input data for calculation are among the mandatory manure administration in NL.		Country level data in FSS; might provide the possibility to track down farm level stats
9	Nutrient application and management	A33 Farm-scale balance for P	Input data for calculation are among the mandatory manure administration in NL.		Country level data in FSS; might provide the possibility to track down farm level stats
10	Nutrient application and management	A38 Farm-scale balance for K	No data		
11	Nutrient application and management	A24 Amount of mineral N applied per hectare of UAA	No data.		Country level data in FSS; might provide the possibility to track down farm level stats
12	Consumption of non-renewable energy	A41 Direct energy consumption	No data.	FADN; FSS	Can be proxied by dividing the sector's energy consumption at country level over farms weighted by energy spendings at farm level from FADN. Spending data missing for Bulgaria, Czech, Denmark, Hungary, Lithuania, Latvia, Poland, Romania, UK; agricultural sector national energy figures missing for Germany.
13	Consumption of non-renewable energy	A41b Indirect energy consumption	No data	FADN; FSS	Several of the components (crop products, pesticides, overall fertilizers) can be approximated using country level FSS data downscaled to farm level using spendings data from FADN.
14	Consumption of non-renewable energy	A46 Energy output	Tonnes of product from FADN; energy contents from various sources	SOSTARE paper and references therein; FADN	
15	Consumption of non-renewable energy	A48 Energy use efficiency	As far as A41(b) and 46 allow: calculation output		
16	Water resource management	A49 Proportion of the farm UAA that is not irrigated in a year	FADN; regional data can be derived from LUCAS	FADN LUCAS	Points with an agricultural land cover (codes B) and signs of irrigation.

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
17	Water resource management	A51 Proportion of the farm UAA that is irrigated with the consumption of energy	No data at farm level. Regional level can be derived from LUCAS.	LUCAS	Points with an agricultural land cover (codes B) and WM_TYPE 2, 3, 4, or 5
18	Water resource management	A52 Proportion of UAA that is irrigated with water tapped from groundwater resources	No data at farm level. Regional level can be derived from LUCAS.	LUCAS	Points with an agricultural land cover (codes B) and WM_SOURCE 1 or 5
19	Agrochemical management	A54 Proportion of UAA not treated with agrochemicals in a year	No data		Limited relevance for CSA
20	Agrochemical management	A55 Frequency of application	No data		Limited relevance for CSA
21	Agrochemical management	A59 Load index for rats	No data		Limited relevance for CSA
22	Agrochemical management	A61 Load index for algae	No data		Limited relevance for CSA
23	Agrochemical management	A90 Load index for honeybees	No data		Limited relevance for CSA
24	Economic indicators	E01 Value of production per hectare	FADN	FADN	Relevant efficiency variable for CSA
25	Economic indicators	E02 Value of production per annual work units	Based on SE131 Total output	FADN	Relevant efficiency variable for CSA
26	Economic indicators	E04 Value added per UAA	SE131 / SE425D	FADN	Relevant efficiency variable for CSA
27	Economic indicators	E05 Value added per annual work unit	SE415/SE025	FADN	Relevant efficiency variable for CSA

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
28	Economic indicators	E03 Farm profitability, calculated as value added per value of production	SE415/SE425D	FADN	Lesser relevance for CSA
29	Economic indicators	E25 Farm household income; earnings before interest, taxes, depreciation and amortization per value of production (EBITDA)	SE415/SE131	FADN	Lesser relevance for CSA
30	Economic indicators	E26 EBIDTA + single farm payment + agri-environment payments per value of production	SE430N	FADN	Lesser relevance for CSA
31	Economic indicators	E27 Dependence on CAP subsidies: (SFP+AE)/(EBITDA + SFP + AE)	(SE430N + SE631 + SE621) / SE131	FADN	Lesser relevance for CSA
32	Economic indicators	E24 Farm business diversification	(SE631+SE621)/(SE631+SE621+ SE430N)	FADN	Although this variable can be calculated from SE variables FADN. Requires a separate calculation module for more complicated farms. Not relevant for CSA, very relevant for SI. Lesser relevance for CSA.
	Ecological indicators	L01 Linear elements	Farm level: included in parcel registration in NL. Regional level: Can be derived from LUCAS	Parcel map; LUCAS	Scope for detailed sentinel data
	Ecological indicators	L02 Areas of natural vegetation	FADN; NL parcel registration. Regional level: CORINE land cover; Sentinel	FADN, parcel map, corine land cover	Scope for detailed sentinel data
	Ecological indicators	L03 Point natural elements	Farm level: detailed land cover map (NL:Top10 / LGN). Regional level: LUCAS		Scope for detailed sentinel data

Input ID	Category	Input description	Proxy data	Reference for proxy data	Comments
	Ecological indicators	L04 Core area of indigenous vegetation patches	No data		
	Ecological indicators	L05 Fractal index	Can be calculated from high-resolution land cover map		Heavy calculation and limited relevance for CSA.
	Ecological indicators	L06 Functional connection between habitat patches	Can be calculated from high-resolution land cover map		
	Livestock	Grazing	LUCAS XXXX	LUCAS XXXX	….

Annex 5: CSA measure implementation

Table A5.1: Level of implementation of bioenergy crops

	Potential farms	Actual farms	
Country	Number	Number	%
BE	11994	184	1.5%
BG	62903	0	0.0%
CY	4613	0	0.0%
CZ	10282	267	2.6%
DK	17461	578	3.3%
DE	74153	8917	12.0%
EL	160992	4151	2.6%
ES	224604	0	0.0%
EE	4120	3	0.1%
FR	128959	4009	3.1%
HU	80407	0	0.0%
IE	7621	167	2.2%
IT	345720	880	0.3%
LT	33061	6	0.0%
LU	193	4	2.1%
LV	13095	7	0.1%
MT	1997	0	0.0%
NL	17459	0	0.0%
AT	23765	3331	14.0%
PL	473808	88	0.0%
PT	41791	0	0.0%
RO	491517	0	0.0%
FI	23950	0	0.0%
SE	10923	518	4.7%
SK	2542	20	0.8%
SI	15609	0	0.0%
UK	34659	301	0.9%
	2318198	23430	1.0%

Table A5.2: Level of implementation of catch crops

	Potential farms	**Actual farms**	
Country	Number	Number	%
BE	13940	1365	9.8%
BG	70338	5144	7.3%
CY	8512	668	7.8%
CZ	11973	816	6.8%
DK	17757	2982	16.8%
DE	90945	20125	22.1%
EL	283076	11791	4.2%
ES	447669	11795	2.6%
EE	4330	641	14.8%
FR	188027	4090	2.2%
HU	90159	5417	6.0%
IE	7669	68	0.9%
IT	585470	5998	1.0%
LT	35812	7019	19.6%
LU	388	35	8.9%
LV	14557	1788	12.3%
MT	2160	0	0.0%
NL	20253	1358	6.7%
AT	32646	6867	21.0%
PL	581017	200284	34.5%
PT	65175	11784	18.1%
RO	685398	41766	6.1%
FI	24314	2107	8.7%
SE	11028	2151	19.5%
SK	2667	383	14.4%
SI	21990	1352	6.1%
UK	36331	736	2.0%
	3353601	348528	10.4%

Table A5.3: Level of implementation of cover crops

	Potential farms	Actual farms	
Country	Number	Number	%
BE	13940	4935	35.4%
BG	70338	7186	10.2%
CY	8512	1700	20.0%
CZ	11973	1410	11.8%
DK	17757	6292	35.4%
DE	90945	25572	28.1%
EL	283076	29643	10.5%
ES	447669	37524	8.4%
EE	4330	1973	45.6%
FR	188027	73029	38.8%
HU	90159	8052	8.9%
IE	7669	1305	17.0%
IT	585470	134203	22.9%
LT	35812	23842	66.6%
LU	388	180	46.5%
LV	14557	6772	46.5%
MT	2160	0	0.0%
NL	20253	2283	11.3%
AT	32646	9369	28.7%
PL	581017	282261	48.6%
PT	65175	17814	27.3%
RO	685398	75783	11.1%
FI	24314	11602	47.7%
SE	11028	7799	70.7%
SK	2667	831	31.2%
SI	21990	5427	24.7%
UK	36331	19601	54.0%
	3353601	796386	23.7%

Table A5.4: Level of implementation of N fixating crops

	Potential farms	Actual farms	
Country	Number	Number	%
BE	23190	17907	77.2%
BG	94302	24741	26.2%
CY	4613	2617	56.7%
CZ	15559	5447	35.0%
DK	22146	6280	28.4%
DE	153128	109661	71.6%
EL	175428	61481	35.0%
ES	286781	65507	22.8%
EE	7123	1037	14.6%
FR	221668	109544	49.4%
HU	82861	23604	28.5%
IE	86501	4258	4.9%
IT	363549	113818	31.3%
LT	59582	9629	16.2%
LU	1400	1074	76.7%
LV	23738	2070	8.7%
MT	1138	795	69.9%
NL	34489	20807	60.3%
AT	77858	39130	50.3%
PL	649539	246662	38.0%
PT	63774	37804	59.3%
RO	1077216	390763	36.3%
FI	35244	4363	12.4%
SE	26700	7405	27.7%
SK	3568	1716	48.1%
SI	38767	13863	35.8%
UK	90119	18959	21.0%
	3719982	1340941	36.0%

Table A5.5: Level of spread of combining permanent crops with annuals

	Potential farms	Actual farms	
Country	Number	Number	%
BE	26226	457	1.7%
BG	91125	10862	11.9%
CY	9808	4731	48.2%
CZ	17163	1534	8.9%
DK	24520	2238	9.1%
DE	171571	11464	6.7%
EL	329711	104773	31.8%
ES	538929	103007	19.1%
EE	7397	810	11.0%
FR	284952	29560	10.4%
HU	93689	11938	12.7%
IE	86501	195	0.2%
IT	680519	253441	37.2%
LT	60738	5575	9.2%
LU	1558	84	5.4%
LV	24409	4375	17.9%
MT	2503	1460	58.3%
NL	43905	1174	2.7%
AT	85516	10972	12.8%
PL	714785	100011	14.0%
PT	96370	38738	40.2%
RO	1031702	171900	16.7%
FI	37303	1192	3.2%
SE	27107	539	2.0%
SK	3676	466	12.7%
SI	43008	19276	44.8%
UK	93005	1357	1.5%
	4627696	892132	19.3%

Table A5.6: Spread of farms with woodlands

	Potential farms	Actual farms	
Country	Number	Number	%
BE	26288	0	0.0%
BG	111230	212	0.2%
CY	10137	0	0.0%
CZ	17163	1641	9.6%
DK	24564	75	0.3%
DE	171571	103275	60.2%
EL	336376	3752	1.1%
ES	545267	22241	4.1%
EE	7483	5654	75.6%
FR	285036	7760	2.7%
HU	98106	9244	9.4%
IE	86501	14916	17.2%
IT	680693	97630	14.3%
LT	60738	13896	22.9%
LU	1558	1131	72.6%
LV	24409	17832	73.1%
MT	2601	0	0.0%
NL	44403	10	0.0%
AT	85516	77537	90.7%
PL	716221	405766	56.7%
PT	96883	29779	30.7%
RO	1119253	7290	0.7%
FI	37303	0	0.0%
SE	27107	0	0.0%
SK	3676	118	3.2%
SI	43008	40988	95.3%
UK	93005	39977	43.0%
	4756098	900724	18.9%

Table A5.7: Spread of farms with deep rooting crops

	Potential farms	Actual farms	
Country	Number	Number	%
BE	26288	10103	38.4%
BG	111230	15663	14.1%
CY	10137	0	0.0%
CZ	17163	6089	35.5%
DK	24564	6751	27.5%
DE	171571	62516	36.4%
EL	336376	16999	5.1%
ES	545267	45277	8.3%
EE	7483	1592	21.3%
FR	285036	100061	35.1%
HU	98106	28136	28.7%
IE	86501	1319	1.5%
IT	680693	25009	3.7%
LT	60738	6437	10.6%
LU	1558	392	25.1%
LV	24409	1482	6.1%
MT	2601	0	0.0%
NL	44403	8473	19.1%
AT	85516	15867	18.6%
PL	716221	111396	15.6%
PT	96883	1290	1.3%
RO	1119253	110660	9.9%
FI	37303	7213	19.3%
SE	27107	6667	24.6%
SK	3676	1878	51.1%
SI	43008	2391	5.6%
UK	93005	16534	17.8%
	4756098	610196	12.8%

Table A5.8: Spread of farms with permanent crops

	Potential farms	Actual farms	
Country	Number	Number	%
BE	26288	1412	5.4%
BG	111230	22941	20.6%
CY	10137	8776	86.6%
CZ	17163	2425	14.1%
DK	24564	3271	13.3%
DE	171571	21275	12.4%
EL	336376	238097	70.8%
ES	545267	309552	56.8%
EE	7483	918	12.3%
FR	285036	70647	24.8%
HU	98106	18030	18.4%
IE	86501	195	0.2%
IT	680693	463702	68.1%
LT	60738	6087	10.0%
LU	1558	221	14.2%
LV	24409	4813	19.7%
MT	2601	1624	62.5%
NL	44403	1756	4.0%
AT	85516	13949	16.3%
PL	716221	134771	18.8%
PT	96883	61599	63.6%
RO	1119253	202883	18.1%
FI	37303	1262	3.4%
SE	27107	559	2.1%
SK	3676	507	13.8%
SI	43008	20091	46.7%
UK	93005	1808	1.9%
	4756098	1613173	33.9%

Table A5.9: Spread of farms with permanent grasslands

	Potential farms	Actual farms	
Country	Number	Number	%
BE	16817	16386	97.4%
BG	65221	27257	41.8%
CY	2038	72	3.5%
CZ	9061	8826	97.4%
DK	10079	7800	77.4%
DE	108160	103899	96.1%
EL	78521	12073	15.4%
ES	129725	78154	60.2%
EE	4270	3342	78.3%
FR	135332	113066	83.5%
HU	30233	7800	25.8%
IE	81458	81387	99.9%
IT	120845	2332	1.9%
LT	41522	19528	47.0%
LU	1322	1322	100.0%
LV	16999	6514	38.3%
MT	577	0	0.0%
NL	26775	25759	96.2%
AT	60842	60242	99.0%
PL	395573	350030	88.5%
PT	44883	27171	60.5%
RO	842634	392337	46.6%
FI	14648	3772	25.8%
SE	18387	16419	89.3%
SK	1583	1025	64.7%
SI	31549	30835	97.7%
UK	64792	61733	95.3%
	2353846	1459078	62.0%

Annex 6: Data Annex

See extra file.

Annex 7: Model Code and Documentation

This annex describes the inputs and steps required to run the inventory and potential calculation scripts.

General description

This R / python tool inventories the uptake of a range of CSA measures, based on the FADN dataset. On a farm level, the presence / absence of a set of measures is recorded, based on the presence of specific crops or land use strategies. Furthermore, the area on which each measure is implemented, is recorded. These basic outputs are summarized and analysed in different ways.

- First, after making an inventory of individual measures, the number of implemented measures per farm is calculated.
- Second, a "benchmark" value is calculated: an area percentage on which a measure could reasonably implemented that is specific to the country and the environmental zone. This only considers farms for which the measure fits in the overall farming strategy.
- Third, measure implementation area per farm is compared to the benchmark value. This comparison yields a potential area for further measure implementation. This is summarized to total areas per NUTS2 region.
- Fourth, for each measure, at NUTS2 level the number of farms below the benchmark is calculated as a percentage of the farms for which the measure fits in the overall farming strategy.

Inputs

- The tool requires raw country-specific FADN files in csv format. Variables used for inventory of measure uptake and potential are listed in Table 1.
- A csv file that links each NUTS2 region to a country-environmental zone stratum (recode.csv)

Table 27- Variables used for inventory of measure uptake and potential

Code	Description	Comment
countryyear		
id	Unique identifier of farm	Anonymous code allowing constant sample
JC150	Subsidies for Meadows+perm. pastures	in EUR
JC151	Subsidies for Rough grazing	in EUR
JC173	Subsidies for Woodland	in EUR
K120AA	Common wheat_AA	in ha
K121AA	Durum wheat_AA	in ha
K122AA	Rye AA	in ha
K123AA	Barley AA	in ha
K124AA	Oats AA	in ha
K125AA	Summer cer_mix. AA	in ha
K126AA	Grain maize_AA	in ha
K127AA	Rice AA	in ha
K128AA	Oth.cereals_AA	in ha
K129AA	Dry pulses AA	in ha
K130AA	Potatoes AA	in ha
K131AA	Sugar beet AA	in ha
K132AA	Oil seed_AA	in ha
K132NFAA	Oil seed_NF - AA	in ha
K133AA	Hops AA	in ha
K134AA	tobacco_AA	in ha
K135AA	oth. indust._crp AA	in ha
K136AA	fresh veg._op.field-AA	in ha
K137AA	fresh veg._mkt gard. AA	in ha
K138AA	fresh veg._und.glas.AA	in ha
K139AA	mushrooms_AA	in ha
K140AA	flowers open_air AA	in ha
K141AA	flowers protected AA	in ha
K142AA	grass seed_AA	in ha
K143AA	other seeds _AA	in ha
K144AA	fodder roots+brassicas AA	in ha
K145AA	Other fodder plants AA	in ha
K146AA	fallow land_AA	in ha
K146OUAA	obligatory_uncultiv. AA	Uncultivated set-aside
K147AA	temporary_grass AA	in ha
K148AA	oth.arab._crops AA	in ha

K150AA	meado.+_perm.past. AA	in ha
K151AA	rough gra-_zing AA	in ha
K152AA	fruit + berry_orchar. AA	in ha
K153AA	citrus orch._AA	in ha
K154AA	olive groves_AA	in ha
K155AA	vines AA	
K156AA	perm. crp._u/protect.AA	in ha
K157AA	nurseries_incl. vines AA	in ha
K158AA	oth. perm._crops AA	in ha
K172AA	occas.let_ting forag.AA	in ha
K173AA	woodland AA	in ha
K182AA	oth. areas_AA	in ha
K281AA	tbl. olives_AA	in ha
K282AA	olives for_oil prod. AA	in ha
K283AA	olive oil_AA	in ha
K285AA	table grapes_AA	in ha
K286AA	grapes qual._wine AA	See K155AA
K287AA	grapes tabl._&oth.w AA	See K155AA
K289AA	quality_wine AA	See K155AA
K290AA	tbl.wine &_oth.wine AA	See K155AA
K291AA	raisins_AA	in ha
K292AA	grapes for quality wine PGI_AA	in ha
K293AA	grapes for other wines_AA	in ha
K294AA	quality wine PGI_AA	in ha
K295AA	other wines_AA	in ha
K314AA	unused permanent grassland with DP AA	in ha
K315AA	Fallow land without any subsidies_AA	in ha
K316AA	Fallow land subject to the payment of subsidies_AA	in ha
K326AA	fodder maize_AA	in ha
K327AA	oth. silage_cereals AA	in ha
K328AA	oth. silage_cereals AA	in ha
K329AA	dry pulses_for fodder AA	in ha
K330AA	oth. prot._crops AA	in ha
K331AA	rape AA	in ha
K332AA	sunflower_ AA	in ha
K333AA	soyaAA	in ha
K334AA	other AA	in ha

K335AA	cabbage_brass.crp AA	in ha
K336AA	leaf veget._AA	in ha
K337AA	tomatoes_AA	in ha
K338AA	oth.veg. grown for fruit/fl.AA	in ha
K339AA	oth.veg.grown for roots/bulbAA	in ha
K340AA	peas,beans_etc. AA	in ha
K341AA	non-perennial fruit AA	in ha
K342AA	flow.bulb_corms&tubers AA	in ha
K343AA	cut flow.&_flow.buds AA	in ha
K344AA	flow.& ornam_plantAA	in ha
K345AA	medicinal plants etc.AA	in ha
K346AA	sugar cane_AA	in ha
K347AA	cottonAA	in ha
K348AA	oth. industrial crops AA	in ha
K349AA	pome fruit excl.table grapesAA	in ha
K350AA	stone fruit excl. olives AA	in ha
K351AA	nuts AA	in ha
K352AA	small fruit_& berries AA	in ha
K353AA	trop.& sub_trop.fruit AA	in ha
K354AA	oranges_AA	in ha
K355AA	tangerine, mandarine, clem. AA	in ha
K356AA	lemons_AA	in ha
K357AA	oth. citrus_fruit AA	in ha
K360AA	Peas,fld beans,. AA	in ha
K361AA	Lentils,ch.peas.. AA	in ha
K362AA	Potatoes/starch AA	in ha
K363AA	Other potatoes AA	in ha
K364AA	Flax/not fib.flax AA	in ha
K373AA	Fibre flax AA	in ha
K374AA	Hemp AA	in ha
K375AA	Sweet corn AA	in ha
NUTS2	NUTS2	NUTS2 region
SE025	Total Utilised Agricultural Area	in ha
SYS02	Farms represented	number of farm represented in the population
TF14	TF14 Grouping	farming type classification
YEAR	Year	accounting year

Procedure overview

- Generic procedures:
  - Country specific csv files are read and merged into a single data frame.
  - The csv file that recodes NUTS2 regions into country-environmental zone strata is read and joined into the data frame.
  - A subset is made with only the variables necessary for CSA uptake and potential inventory.
  - A benchmark value is set. The benchmark should be specified as a percentile and represents an fraction of the farm UAA that farms that could implement a measure could dedicate to it. The specified percentile is calculated for country-environmental zone strata, for each measure individually.
- Measure specific procedures:
  - Inventory and potential calculation procedures:
    - A subset is made only including the TF14 types that can logically implement the measure, and only including the variables relevant to assess this specific measure.
    - Area on which the measure is implemented is calculated, by summing up the areas of the individual crops that represent the measure. This area is stored as a variable.
    - A "measure presence" variable is created that is zero if the area is zero, or one if the area is larger than zero.
    - The area fraction of the farm dedicated to the measure is calculated by subdividing the measure area by the UAA.
    - Using the predefined benchmark percentile, the benchmark area fraction is calculated for country-environmental zone strata.
    - The measure implementation fraction per farm is subtracted from the benchmark. The result is multiplied by the UAA. If this value is larger than zero, i.e. the farm has a smaller fraction of the UAA dedicated to the measure than specified by the benchmark, the area is stored as variable that represents the potential area for measure implementation at farm level. A variable is calculated that indicates if a farm scores below (1) or above (0) the benchmark.
  - Summarizing procedures:
    - The measure implementation area is aggregated to NUTS2 region, by multiplying with the SYS02 variable (number of farms represented by the sample farm) and calculating a sum.
    - A fraction of farms with potential for measure implementation is created, using the "below benchmark" variable and the SYS02 variable. This is done aggregated at NUTS2 level.
    - The potential area for measure implementation is aggregated to NUTS2 level. Farm specific potential areas are multiplied by SYS02 and a sum is calculated.
- Generic summarizing procedures:
  - After all measures are inventoried, the "measure presence" variables for all measures are added up and stored as an overall "measure count" variable.

Outputs

- all_fadn.csv: farm level dataset with all observations in Europe with all relevant variables.
- count_measures.csv: farm level dataset with farm ID, NUTS2-Environmental zone variable, area of each measure, and number of measures implemented at the farm.
- Folder OUTPUT_XX (XX being the specified benchmark percentage):
  - Folder Farms:
    - measure.csv: farm level dataset, measure specific. Specifies the measure area, benchmark area, potential area, and position relative to benchmark (1: below; 0: above). Furthermore, contains a set administrative variables that could be used for further indicator calculation: farm ID, NUTS2 and environmental zone, SYS02, TF14, and a variable indicating if the farm, based on its TF14 type, could logically implement the measure.
  - Folder NUTS2:
    - nutseco_measure.csv: NUTS2 level dataset, measure specific. Specifies the total measure area in hectares and as a percentage of the UAA, the benchmark area, the potential area, and the percentage of farms under the benchmark.
    - nuts_summary.csv: NUTS2 level dataset. Specifies area (ha), farms under benchmark (fraction), and potential area (ha) for each measure.

Instructions

An R script is used to create the FADN dataset, after which calculations are done in python.

- prepare_data.R requires:
  - A working directory that contains:
    - A folder called SO (which is consistent with standard FADN naming conventions) with raw FADN csv files, named CNTXXXX.csv. CNT is the ISO3 country code, XXXX the year of analysis. This is consistent with standard FADN naming conventions. Currently, the year 2013 is implemented, but by find-replace, the script can be used for any other year, lest the FADN variable coding and NUTS2 classification remains unchanged.
    - The file recode.csv, that specifies in which country-environmental zone stratum each NUTS2 region is located.
    - The script prepare_data.R.
  - Library pacman should be installed.
- The script can be run in any R environment, such as RStudio.
- The script automatically sets the working directory to the location of the source files listed above.
- The output file all_fadn.csv is written to the working directory.
- ind_farms.py requires:
  - a working directory that contains the file all_fadn.csv
  - libraries pandas and tqdm.
- The script can be run from a command prompt or any gui.
- Before running, the benchmark should be specified in the line specifying "percentile = …"
- The output csv files can be joined to the NUTS2 shapefile in any GIS environment.

Annex 8: Overview of carbon labels

See extra file

Annex 9: Carbon labelling mapping exercise

<table>
<tr><th>Category</th><th>Label characteristics</th><th colspan="2">Policy options</th></tr>
<tr><td rowspan="5">Design & Scope</td><td>1) Certification scope:

This characteristic indicates whether the label certifies GHG emission related indicators only or whether other indicators are included as well (such as measures enhancing climate adaptation, water conservation, environmental protection, etc.).

Mutually exclusive options</td><td colspan="2">a) GHG emission related indicators only

b) Combination of GHG emission related and other indicators (tbd)</td></tr>
<tr><td>2) Value chain covered

This characteristic indicates whether the label requires a full lifecycle analysis, whether only parts of a product’s life cycle are taken into account or whether the label certifies the adoption of climate smart practices

Mutually exclusive options</td><td colspan="2">a) LCA

b) Part of lifecycle (e.g. limited to on-farm emissions)

c) Recognised climate smart practices</td></tr>
<tr><td rowspan="3">3) Certification requirements and reporting obligations

This characteristic indicates
A. what norm(s) the farm/product needs to adhere to in order to be certified and</td><td>A. Certification requirements</td><td>B. Reporting obligations</td></tr>
<tr><td>a) Certified carbon footprint</td><td>a) Data on GHG emissions</td></tr>
<tr><td>b) Emission reductions compared to (evolving) product or farm benchmark (output criteria-based scheme)</td><td>b) Data on GHG emissions</td></tr>
</table>

Category	Label characteristics	Policy options	
	B. Which (sets of) data the farmer/producer is required to report in case the data is not available from other sources Multiple options can be combined	c) Adoption of a set of recognised climate smart practices (input criteria-based scheme)	c) Farm-level data on recognized climate smart practices
		d) Carbon offsetting	d) Data on soil sequestration and/or offsets
		e) Level of renewable energy use compared to (evolving) product or farm benchmark	e) Data on renewable energy use
		f) Reducing food miles compared to product benchmark	f) Data on distance travelled
	4) **Means of verification** This characteristic indicates on which data verification is based and how this can be verified Multiple options can be combined	a) Spatial data b) Existing (farm) databases c) Farmer’s declarations d) On-site visits	
Governance	5) **Administering organisation(s)** This characteristic indicates the type of the organisation(s) responsible for the label, and whether this is a private, governmental or non-governmental organisation Multiple options can be combined	d) Governmental agency d) Private agency d) Non-profit organisation	
	2) **Verification mode**:	a) Third party certification	

Category	Label characteristics	Policy options
	This characteristic indicates whether the label is verified by a third party, by the administering organisation or by the producer itself Multiple options can be combined	b) Verification by the administering organisation a) Self-certification
	3) **Standard setting norm(s) for verification**: This characteristic indicates if and in case that yes, which internationally recognised norms are used to verify the emission reductions, environmental performance, emission offsets, … Multiple options can be combined	a) None b) ISO norms c) Publicly Available Specification (PAS) d) Greenhouse Gas Protocol b) IPCC Guidelines for National Greenhouse Gas Inventories
	4) **Standard setting norm(s) for certification bodies** This characteristic indicates which internationally recognised norms are used to ensure the competence, consistency and impartiality of third party bodies verifying emission reductions, environmental performance, emission offsets, etc. Multiple options can be combined	a) None b) ISO norms c) ISEAL Code of Good Practice for Setting Social and Environmental Standards e) Environmental Management System (EMS) Auditor
Information to end user	5) **Label features** This characteristic indicates what information the label's logo on a package or organisation's communication tools conveys to the end user Multiple options can be combined	a) Certification logo without additional info b) Stoplight label (Top, Medium or Lower category of environmental/climate performance) c) Carbon footprint (communication of the amount of emissions associated with a product or farm)

Category	Label characteristics	Policy options
		d) Carbon neutrality e) Climate-friendly production process (verified emission reductions, climate smart practices, etc.)

Annex 10: Overview of LIFE projects

Name	Description	Relevance	URL	Duration
AGRICLIMATECHANGE - *Combating climate change through farming: application of a common evaluation system in the 4 largest agricultural economies of the EU* ***LIFE09 ENV/ES/000441***	The LIFE+ AgriClimateChange project was implemented in order to demonstrate that agriculture can tackle climate change effectively and that actions by the farming sector are not a constraint, but in fact can represent an economic opportunity for farmers. The project provided effective tools (such as the AgriClimateChange Tool) that help to measure energy and GHG emissions balances/reductions at farm level. It furthermore identified agricultural support measures that contribute to fight climate change, confirmed opportunities for improving EU legislation and regulation in this field, and raised considerable awareness among influential stakeholders and decision-makers about effective and quantifiable climate action on Europe's farms.	• Assessment of GHG emissions through life-cycle analysis • Development of evaluation tools measuring energy and GHG emissions balances/reductions at farm level • No development of ecolabel	www.agriclimatechange.eu	Sept. 2010-Dec. 2013
AGROLCA-Manager – *Environmental Sustainability Software Tool for the Agroindustrial Sector* ***LIFE10 ENV/ES/000486***	The goal was to produce a tool that can help primary sector companies measure, demonstrate and reduce their environmental impact, as well as improve their economic and social impact. The project developed a software to enable agro-industrial companies to conduct life cycle assessments in their sector. It would support them in activities such as calculating their carbon footprint and obtaining ecolabels for marketing purposes. The project aimed to find an optimum balance between the usability of the tool in the sector and the accuracy and usefulness of the data provided, both for the management of environmental impacts and for eco-labelling. The project developed an eco-innovation software tool for life cycle assessment in the agro-food sector, demonstrated environmental life cycle assessments in a winery and on a farm, identified improvement actions for areas of high environmental impact and reduced environmental impact of primary sector food producers.	• Assessment of GHG emissions through life cycle analysis • Software tool assisting companies to conduct life cycle analysis •	www.agrolcamanager.com/?lang=en	Sept. 2011-Aug. 2014

Name	Description	Relevance	URL	Duration
	The AGROLCA-Manager software tool calculates 15 sustainability indicators from the life cycle assessment approach, including: carbon footprint, water footprint (stress and green, blue and grey water), CO2 emissions and flow, energy, phytosanitary (number of treatments and amount applied) and Ecotoxicity (freshwater, sea water, terrestrial- and human toxicity). The tool is the first one that provides suggestions for reducing the environmental impact through the implementation of Best Available Techniques (BATs) and offers information about the legislation affecting these processes. In order to ensure the continued use of the tool, the beneficiary has designed the software tool to take account of the data usually recorded by the farmer in the regular farm registers.			
HAproWINE - *Integrated waste management and life cycle assessment in the wine industry: From waste to high-value products* ***LIFE08 ENV/E/000143***	Using real data from participant wineries, the environmental impacts of wine product systems were assessed using a life cycle analysis methodology. As a result, an Ecolabelling Programme, based on Product Category Rules (PCR), combining Type I and Type III eco-labels (ISO 14025) was designed and tested. The eco-labelling scheme has raised considerable interest in international forums where it has been presented (e.g. 2012 LCA Food Conference and 2013 Life Cycle Management Conference). The PCR were also submitted to AENOR (Spanish standardisation body), which indicated interest in adopting these rules under its own eco-labelling system. The Environmental Product Declaration (EPD) International System programme has agreed to take the PCR into account when reviewing their rules for developing environmental product declarations for wine, which ensures the continuous use of the PCR after the end of the project end.	• Life cycle analysis methodology • Ongoing discussion to include the measurement of GHG emissions • Testing of Ecolabelling Programme based on Product Category Rules (PCR) • Integrated in overview of carbon labels	www.haprowine.eu	Jan. 2010-Jan. 2013

Name	Description	Relevance	URL	Duration
ECOMARKET - ***Implementation of ISO 14001 - EMS, of eco-labelling and of ecological models as tools based on sustainability indicators in public administration and food markets*** ***LIFE02 ENV/RO/000462***	The project sought to demonstrate how eco-labels could be an effective instrument in moving the production and trade of agricultural and industrial products in Romania towards sustainability. As a key tool for the implementation of the environmental management system (EMS), the project developed an ecological market model and a voluntary eco-labelling scheme (VES) for traders in food markets, which improved the environmental protection performance of food markets. These were tested in five pilot units where ecological certificates were awarded for conformity to the standards devised. The system ensures continuous efforts from the shops in the markets as the certificates are withdrawn if the environmental performance falls below the standards. The tests showed that the use of the voluntary eco-labelling generated better ecological performance of food markets as shown by improved scores against the performance criteria for resource consumption, environmental protection and hygiene. Attitudes and awareness in the food markets with regards the environment and public health were seen to have improve.	• Development of ecolabelling schemes • No life cycle analysis • No assessment of GHG emissions	life-ecomarket.pmb.ro	Nov. 2002-Apr. 2005
Ecotrade - ***Ecolabelling of retail trade*** ***LIFE00 ENV/DK/000374***	The project aims at improving and adjusting existing environmental assessment methods and ecolabelling schemes in order to elaborate concise instruments for the reduction of environmental impact in retail trade and hence derived private consumption. The project developed an environmental assessment method based on earlier and existing experiences. The environmental assessment method was tested in five retail stores in Denmark. Based on results from this test the method was adjusted and tested in 25 retail stores. The feasibility of the method was evaluated. Finally, a voluntary eco-labelling scheme was developed and the achieved results disseminated. The project has succeeded in delivering an environmental assessment method for retail trade based on criteria including selection of eco-labelled products available in the stores. Furthermore, the environmental impact from factors such as energy and heat consumption and waste handling were assessed. The project developed a voluntary eco-labelling scheme, including a set of formal rules for entering the scheme.	• Improvement of ecolabels • Development of ecolabel • Focus on retail stage of life cycle analysis • No assessment of GHG emissions • Ecolabel not used	ecotrade.dk	Sept. 2001-Aug. 2004

Name	Description	Relevance	URL	Duration
	By the end of the project the tools for eco-labelling are available for use however there are no shops using the scheme as the partner Panduro, a hobby material retailer, ceased using the scheme by the end of the project.			
fertiLIFE - *Sustainable fertilisation of an intensive horticultural basin through an innovative management system of the local vegetal waste bio-mass utilising an existing composting plant and supporting a permanent info-structure* ***LIFE02 ENV/IT/000089***	The fertiLIFE project aimed to conduct a survey of all green waste produced locally and to develop an information system which allows for the utilisation of the compost in the same fields where it originated. Demonstration of the effectiveness of the local bio-masses system would include an economic analysis of costs and benefits taking into account profits, chemical fertilisation and waste disposal cost reduction and the potential for greater intakes from the sale of an organic production with a specific label of origin. This compost was exclusively utilised on selected fields and horticultural products obtained from them were evaluated, packed and sold utilising the specific trade label "fertiLIFE".	• Development of a trade label • Development of information system for local compost utilisation • No assessment of GHG emissions	Expired	Dec. 2002-Feb. 2006
Green Drachma II – *Promoting sustainable development in the Region of Halkidiki through Concerted Pilot Actions on Integrated Product Policy Tools* ***LIFE04 ENV/GR/000145***	The Green Drachma II project aimed to improve the competitiveness of local enterprises from tourist accommodation (hotels), farmers and agro-food processing industries. At the same time the project contributed to environmental protection and sustainable development of the region of Halkidiki, Northern Greece. This was to be achieved by: • Promoting the implementation of Integrated Product Policy (IPP) tools i.e. ecolabel (in tourist accommodation), EMAS/ISO 14001 (in food processing companies) and EUREPGAP (in the farming sector) • Mobilising and linking tourism enterprises with local agricultural and food industries • Carrying out actions to ensure wide dissemination of the project's results in Greece and Europe	• Promotion of ecolabels • No development of ecolabel • No assessment of GHG emissions	Expired	Oct. 2004-Dec 2006

Name	Description	Relevance	URL	Duration
LifeCiP (LCiP) - *Life Cycle in Practice* ***LIFE12 ENV/FR/001113***	The general objective of the LCiP project was to help small and medium-sized enterprises (SMEs) in France, Belgium, Portugal and Spain to reduce the environmental impacts of their products and services in the building/construction, energy equipment and waste management sectors through the application of lifecycle approaches – including LCA, eco-design and environmental labelling.	• Life cycle analysis • No assessment of GHG emissions • Assistance in obtaining ecolabels	www.lifelcip.eu	Sept. 2013-Jun 2016
LIFE FOODPRINT - *Development of an integrated strategy for reducing the carbon footprint in the food industry sector* ***LIFE13 ENV/GR/000958***	The main objectives of the LIFE FOODPRINT project were to evaluate the carbon footprint of the pastry and flour food industry sector along the production, and supply chain, and to increase competitiveness through the development of an innovative software tool enabling the reliable determination and evaluation of the carbon footprint of pastry and flour food products, considering direct and indirect activities (e.g. energy consumption, water and wastewater management). The project introduced the first Greek and Italian company that have effectively lowered the carbon footprint of their products, implemented the carbon footprint offsetting programme and successfully labelled them for the Greek and Italian markets. A specific objective was to engage key stakeholders to ensure verification and promotion of results such as the uptake and wider use of the software tool and the labelling of food products with their carbon footprint.	• Carbon footprint label • Assessment of GHG emissions • Integrated in overview of carbon labels • Software tool assessing product carbon footprints	www.foodprint.gr/index.php/en	Sept. 2014-Apr. 2018

Name	Description	Relevance	URL	Duration
OLIVE4CLIMATE - ***Climate Change Mitigation through a Sustainable Supply Chain for the Olive Oil Sector*** ***LIFE15 CCM/IT/000141***	Quantitative assessment of the related carbon footprint of the production of olive oil. Strategies for sustainable production of olive oil were tested in Italy, Greece and Israel, as well as the uptake of secondary products derived from integrated cultivation systems. A life cycle assessment was conducted, allowing the quantification of the carbon sequestration potential in the olive groves and providing the necessary information to define a technical protocol, which can be replicable in different production and environmental contexts. A handbook for the sustainable management of olive groves, covering aspects such as the olive oil value chain, soil and waste management, and carbon credits, was drafted. The project led to: • The demonstration of a series of replicable solutions and protocols for sustainable management of the olive oil value chain in different environmental and climatic conditions in the Mediterranean area • The creation of numerical models to define the carbon sequestration capacity of olive trees and optimize the planting of new olive trees • The drafting of a greenhouse gas emission monitoring plan for the olive oil value chain, with the involvement of producers • Definition of a labelling system and quality assurance schemes based on the life cycle analysis and the carbon footprint evaluation • Support to the inclusion of olive groves in the voluntary market of carbon credit certification, by reducing emissions and enhancing carbon storage capacity	• Assessment of GHG emissions through life cycle analysis • Carbon footprint label	olive4climate.eu/en	Jul. 2016-Jun 2019
SINERGIA - ***SYNERGY, Quality and respect for environment*** ***LIFE03 ENV/E/000085***	The project established the basis for an environmentally friendly production system for vitiviniculture in La Rioja (ES) as well as work practices that can be implemented in other sectors and regions of the EU.	• Recommendation on best environmental practices • Life cycle analysis	www.lifesinergia.org	Sept. 2003-Jun. 2006

Name	Description	Relevance	URL	Duration
	Technical best practices for environmentally friendly production in vitiviniculture, based on the analysis of their environmental, technical and economic viability were identified. This work enabled the elaboration of a model for environmentally friendly wine production. These practices have been included in various manuals, with recommendations for each practice. The project designed and validated a System of Control and Certification which sets up the mechanisms for compliance with the production model defined during the project. However, the development of the control system and label which guarantees the origin of the product was not as effective as planned due to limitations related to the legal framework in Spain. Nevertheless, the work done has been valuable and has permitted to set the basis for integrating such a system into the national regulations. The life cycle analysis of wine permitted the identification of the most significant impacts of the wine production process, such as the consumption of energy and materials, chemical products use, etc.	• No assessment of GHG emissions • Planned development of an ecolabel but not materialised		

Annex 11: Interview guide

The interview guide in this Annex lists the initial policy options presented to interviewees. It should be noted that the options presented as well as the categorization evolved along with the insights gathered during the course of the project.

Introduction:

At Ramboll we are conducting a study on climate smart agriculture (CSA) for the European Commission. CSA aims to support **food security** while at the same time responding to the need for **adaptation** and **reducing GHG emissions**.

The objective of the study is to build and test **a monitoring tool for climate smart agriculture in the European farming sector** and to propose a **climate smart agricultural label** to potentially **incentivize farmers** to adopt climate smart practices and **inform consumers** on the climate impact of agricultural products.

We have explored the **use of different farm carbon tools** and have **collected and harmonized relevant data** for calculating **farm carbon balances**.

As a first step investigating the potential for a climate smart agriculture label we have **reviewed 57 existing carbon labels** (both food and non-food). On the basis of this we have listed potential **options for the design** of a climate smart agriculture label.

In addition to general questions on the **barriers and opportunities** of carbon labels certifying agricultural products, I would like to ask you questions about these options in order to draw on your expertise to **select the most feasible** policy options.

N.B. Text in italics is for interviewers only and not to be read out as part of question.

Respondent:
Organisation and position:
Date of interview:
Interviewer:

GENERAL QUESTIONS

1. **Can you please describe the work you have been conducting on carbon labels and/or climate smart agriculture?**

2. **How do you assess the impact of carbon labels in general?**

Prompt: Assess impact on GHG reductions

3. **How do you assess the impact of climate smart agriculture labels?**

Prompt: Assess impact on GHG reductions

4. **Do you think it makes sense for a climate smart agriculture label to include certification of climate adaptation measures? Do you think this could incentivise farmers to adopt climate adaptation measures?**

Prompt: examples: water resource management, soil management, drought management plans, crop diversification, early warning systems, risk management, …

Do you think this would make sense form an economic perspective?

	5. Do you think consumers are prepared to pay a price premium for carbon footprint labels on food products? **6. In order for farmers to be incentivised to take up actions to reduce GHG emissions, do you think additional financial support is needed on top of a higher farm gate price?** *If yes*: **Which type of support?**
	POLICY OPTIONS
General questions	**7. What type of label do you consider most effective?** a) A label on product level b) A label on farm level
Label characteristic	
Labelling and certification organisation(s)	**8. Which of the following types of labelling and certification organisations do you consider to be preferable with regards to the credibility of the label?** **Why?** a) A governmental agency b) A private agency c) A non-profit organisation
Verification mode	**9. Which of the following verification options do you consider to be preferable with regards to the credibility of the label?** **Why?** a) Third party certification b) Verification by the administering organisation c) Self-certification
Standard setting norm(s) for verification	**10. Do you consider (a) standard setting norm(s) for verification to be necessary?** *If no:* **Why not?** *If yes:* **Which of the following standard setting norm(s) would you recommend a label to apply?** **Why?** a) ISO norms b) Publicly Available Specification (PAS) c) Greenhouse Gas Protocol

	d) IPCC Guidelines for National Greenhouse Gas Inventories
Standard setting norm(s) for third party verification bodies	**11. In case the verification is done by a third party verification body, do you consider the adherence to (a) standard setting norm(s) to be necessary?** *If yes:* **Which of the following standard setting norm(s) would you recommend a label to apply?** **Why?** a) ISO norms b) ISEAL Code of Good Practice for Setting Social and Environmental Standards c) Environmental Management System (EMS) Auditor
Certification procedure	**12. Which of the following actions are suited to demonstrate adherence to the label's requirements?** **Why?** a) Completing an application procedure b) Filling out a questionnaire c) Making an official commitment d) Setting up a management plan e) Using a specific calculation toolkit f) Adhering to a code of conduct g) Implementing a specific guidance document/reduction programme
Value chain covered	**13. Do you consider a full life cycle analysis to be essential for a label to be credible?** **Why (not)?**
GHG emission information obligation	**14. What type of information regarding a product or farms' GHG emissions should a climate smart agriculture label require from farmers?** **Why?** **Do you know of any differences in impact?** a) Emission verification *Prompt: A product or farm's emissions have been verified* b) Verified emission reductions *Prompt: A product or farm's achieved emission reductions have been verified* c) Carbon content *Prompt: The exact emissions of a product or farm have been communicated* d) Details of offsets *Prompt: Details of emission offsets related to a product or farm have been communicated* e) Share of renewable energy use *Prompt: The share of renewable energy use related to a product or farm operations have been communicated*

	f) Distance travelled *Prompt: The distance travelled by a product has been communicated* g) Recognized climate smart practices *Prompt: Recognized climate smart practices adopted at the farm or related to the manufacturing of a product have been communicated*
Certification scope	**15. Do you consider a label that covers one or several of the following issues in addition to climate impact to be more credible?** **Why (not)?** a) Adaptation indicators (land use planning, water use, soil conservation, resource efficiency, renewable raw materials, renewable energy use; ecosystem conservation, …) b) Environmental protection (the product is part of the x best percentage regarding specific issues e.g. impact on water, health, resources, …) c) Waste minimization d) Air pollution prevention e) Water pollution prevention f) Environmental policy and permit compliance g) Promotion of social change h) Supply chain information i) Chemical use j) Social justice k) Ecosystem conservation l) Human health m) Wastewater treatment n) Waste management and reduction
Label features conveying information to the end user	**16. Which of the following information should be conveyed by the label's logo?** **Why?** a) The product is manufactured/farm is operating in an environmentally friendly (and socially just) way b) The product is manufactured/the farm is operating in a climate friendly way (emitting less CO2 than similar products/farms) c) The product or farm is categorised in the Top, Medium or Lower category of environmental/climate improved performance ("stoplight" label) d) The product's carbon content/farm's emissions e) The product is produced/farm operates in a carbon neutral way
CONCLUDING QUESTIONS	
	17. Do you think of specific good practices regarding carbon certification we have not addressed in this interview? **18. Is there anything else you would like to add?**

Annex 12: List of Interviewees

Organization	Expertise	Interview held
Western Washington University, Department of Business and Economics	Consumer behaviour and policy design	4/09/2018
Vanderbilt University, Law School	Carbon Labelling	6/09/2018
OECD, Trade and Agriculture Directorate	Environmental Labelling	7/09/2018
Social and Environmental Research institute (SERI)	Determinants for environmental behaviour	17/09/2018
Sigill Kvalitetssystem AB	Environmental labelling	8/10/2018
Olive4climate LIFE project	(Olive oil) Supply chains	8/10/2018
Wageningen University, Department of Environmental Sciences	Climate Smart Agriculture	13/11/2018
Lund University, International Institute for Industrial Environmental Economics	Ecolabel evaluation	14/11/2018
Aarhus University, Department of Management	Environmental and organic labelling	16/11/2018
Luke, Natural Resource Institute Finland	Consumer communication on environmental impacts	30/11/2018
University of Helsinky, Department of Agricultural Sciences	Life Cycle Assessment and environmental footprint	5/12/2018

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