Climate-Smart Agriculture Solutions Database and Spatial Solution Finder

Deliverable 1.2.6_Flagship:CSAb report SDB-SSF
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Photo cover: cows in a dairy farm in the eastern part of The Netherlands. Photo: Simone Verzandvoort, 2014.

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Acronyms and abbreviations

BaU	business-as-usual
CO2eq	CO2-equivalent
CSA	climate-smart agriculture
GHG	greenhouse gas(es)
SDB	Solutions Database
SSF	Spatial Solution Finder

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Executive summary

The aim of CSA Booster is to facilitate a transition of the European agro-food sector towards climate-smart agriculture (CSA), by providing knowledge, information and access to CSA solutions to actors along the major agricultural value chains. This requires spatial, contextual information on farming activities, environmental conditions, issues and opportunities related to climate change in regions across Europe. Farmers and related actors in the agricultural value chains have difficulties in finding solutions which fit farms and regions in the current overload of information on technologies and solutions for sustainable and climate-friendly farming.

As a first guidance to farmers, advisors and policy planners in the multitude of information on climate-smart farming, the CSA Booster developed a webtool to find prior 'baskets of options' from a limited set of CSA solutions for typologies of regions and farms in Europe. The typologies consists of livestock production zone or the profile of greenhouse gas emissions from a farm. The first version of the webtool, presented in this report, is focussed on the dairy sector as one of the agricultural sub-sectors with a high potential for climate change mitigation and adaptation.

The webtool consists of 7 navigation steps, of which the first 4 lead to a first indication of potential CSA solutions for a selected region of farm GHG-emission profile. These 4 steps were developed in 2017 and are presented in this report. Navigation steps 5-7 lead to a more refined recommendation of CSA solutions and an impact assessment, and are planned to be developed in 2018 and beyond. The more refined recommendation is achieved through a broker system to obtain a limited set of tailor-made solutions for a specific user, based on a matching of user preferences with characteristics of the CSA solutions in the CSA Solutions Database.

The current version of the 'CSA Spatial Solution Finder' discloses 32 CSA solutions at farm level against a background of maps on livestock production zones in Europe, greenhouse gas emissions from agriculture, and several maps on environmental conditions. The solutions are documented in an online database (the 'CSA Solutions Database') on a.o. cost effectiveness, unitary costs, barriers, co-benefits and impacts on the three dimensions of climate-smart agriculture: productivity, mitigation and adaptation. This report presents the CSA Spatial Solutions Finder and its underlying CSA Solutions Database, and discusses opportunities for improvement of the content, functionality and operation in combination with the Open Innovation Platform, the CSA Matchmaking Service, and the CSA Regional Hubs.

1 Introduction

The vision of the CSA Booster Flagship is that by accelerating the adoption of CSA solutions in Europe and beyond, the European agricultural sector will be able to substantially reduce GHG emissions, increase climate resilience and secure food production. The aim of CSA Booster is to facilitate a transition of the European agro-food sector towards this situation, by providing knowledge, information and access to CSA solutions to actors along the major food value chains. This requires spatial, contextual information on farming activities, issues and opportunities related to climate change in regions across Europe.

Climate smart agriculture (CSA) solutions can provide an alternative to farmers who are considering ways and strategies to change their farm management by either adopting new technologies or more advanced or innovative management. A challenge that many farmers currently experience is an overload of information on technologies and solutions for sustainable and climate-friendly farming, from which they cannot easily filter out what works for their enterprise and what not.

The objective of this activity under the CSA Booster is to develop a webtool, the 'CSA Spatial Solution Finder' to support advisors, farmers and policy planners in finding CSA solutions that fit specific sectoral, spatial and regional (environmental, system and economic) conditions. At present the webtool focusses on the dairy sector. The webtool discloses 32 CSA solutions at farm level for the dairy sector, which are documented in the 'CSA Solutions Database'. The information provided on the CSA solutions includes impacts on the three pillars of climate-smart agriculture: productivity, mitigation and adaptation potential. These impacts are expressed relative to the business–as–usual situation of farm management.

The work was conducted by WENR and South Pole in a joint effort. While WENR was the task lead and mainly responsible, South Pole supported the selection of solutions and the research on CSA solutions.

The CSA Spatial Solution Finder consists of 7 components, as described in the deliverable on Task 2.5 for the CSA Booster Flagship in 2016[1] (Figure 1). The project team developed components 1 to 4 in 2017. This report describes these components of the CSA Spatial Solution Finder and the CSA Solutions Database, in the state of development at the end of 2017 (chapters 2-4). An outlook is given to further editions to be developed in 2018 and beyond in chapter 5.

[1] Verzandvoort, S., Walvoort, D. and Kuikman, P. 2016. CSA Booster – Storyboard for the Spatial Solutions Finder. Task 2.5 Solutions database and matchmaking. Climate-KIC and WENR, 16 pp.

Figure 1 Design of the CSA Solution Finder as presented in Deliverable 2.5 of the CSA Booster Program in 2016.

1.1 Definitions

A few key terms essential for understanding the functioning of the CSA Solutions Database and Spatial Solutions Finder are defined in this section.

- Climate-smart agriculture (CSA) is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. The definition of the three pillars of CSA is taken from FAO (2013)[2]:
    1. Productivity: sustainably increasing agricultural productivity to support equitable increases in farm incomes, food security and development;
    2. Mitigation: reducing greenhouse gas emissions from agriculture (including crops, livestock and fisheries);
    3. Adaptation: adapting and building resilience of agricultural and food security systems to climate change at multiple levels.

- The term 'solution' or 'measure' refers to hardware technologies, software technologies, services and management practices in agricultural value chains.
- Agricultural 'practices' refer to the agronomic management techniques used on farms, e.g. manure storage and processing, tillage.

[2] Fao.org – Sourcebook on Climate-Smart Agriculture, Forestry and Fisheries.

2 Approach

The CSA Spatial Solution Finder (www.csaspatialsolutionfinder.org) is a web-based spatial tool aiming to help advisors, farmers and policy planners find CSA solutions which fit farmers and regions. It is based on state of the art (geo)datasets of environmental and socio-economic conditions (partly open access, partly derived from previous research) and open source web-technology. The philosophy of the tool is to combine existing datasets with contextual information on the region of interest with personalized information entered by the user, with the aim to provide a suitable basis for offering a basket of options for CSA solutions. The basket of CSA solutions is recommended based on the GHG emission profile of a farm (derived from the Cool Farm Tool portfolio for the farm), if available, or of the region where the farm is located (derived from the INRA map of livestock production zones[3]). The design enables embedding the tool in the Open Innovation Platform of the CSA Booster.

[3] Dumont, B. et al. 2016. Rôles, impacts et services issus des élevages en Europe. INRA (France), 1032 pages.

3 CSA Solutions Database

The CSA solutions disclosed in the CSA Spatial Solution Finder are drawn from a database with solutions for mitigation and/or adaptation to climate change in agriculture: the CSA Solutions Database. The CSA Solutions Database can be continuously updated during the lifetime of the CSA Booster. In 2018, an interface will be built to facilitate data entry for solutions.

At present, the CSA Solutions Database includes 32 solutions selected from the 'long-list' of 100 solutions inventoried for the CSA Booster in 2016[4]. This number is in accordance with the assignment from Climate-KIC to document 25-35 CSA solutions. Five of these solutions were selected based on an outstanding potential for adaptation.

This chapter describes the selection procedure that was applied to select solutions for the initial version of the CSA Solutions Database, and its structure and content.

3.1 Selection procedure

In order to select around 25-35 CSA solutions the following approach was used:

- Clustering of the CSA solutions into clusters which are recognisable for actors in dairy farming;
- Selection of 25-35 'best practice' solutions from the long-list of 100 solutions from 2016 by experts in the domain of agriculture and climate change
- Verification of the selection with recommendations from leading industries and institutions such as the Global Research Alliance on Agricultural Greenhouse Gases (GRA), the Sustainable Agriculture Initiative Platform and the FAO.

Clustering

The solutions in the list of 100 compiled in 2016 were clustered into clusters representing the components of dairy farms in Europe in order to make them recognisable for farmers and actors related to dairy farming. The clusters were defined based on the most recent overviews of mitigation measures for the dairy sector in Europe (Lesschen & Kuikman, 2017 and GRA and SAI Platform, 2013):

- Animal/herd management
- Feed management
- Manure management
- Stable design
- Fertilization
- Pasture management
- Soil management
- Crop management
- Water management
- Innovations
- Breeding
- Enteric fermentation

For the selection of the CSA solutions we focused on 'best practice solutions'. 'Best practice' indicates that the solution has been successfully implemented in diverse contexts (farm type, size, intensity, environmental zone, social structures) (GRA and SAI Platform, 2013). CSA solutions in the clusters Innovations, Breeding and Enteric fermentation were still in the pilot phase or 'proof of concept'

[4] Sikirica, N. et al., 2016. CSA Booster: Solutions Database Report on Task 2.5. Climate-KIC and Wageningen Environmental Research. 31 pp.

phase, and were therefore discarded. The final composition of clusters with their interrelations is shown in Figure 2.

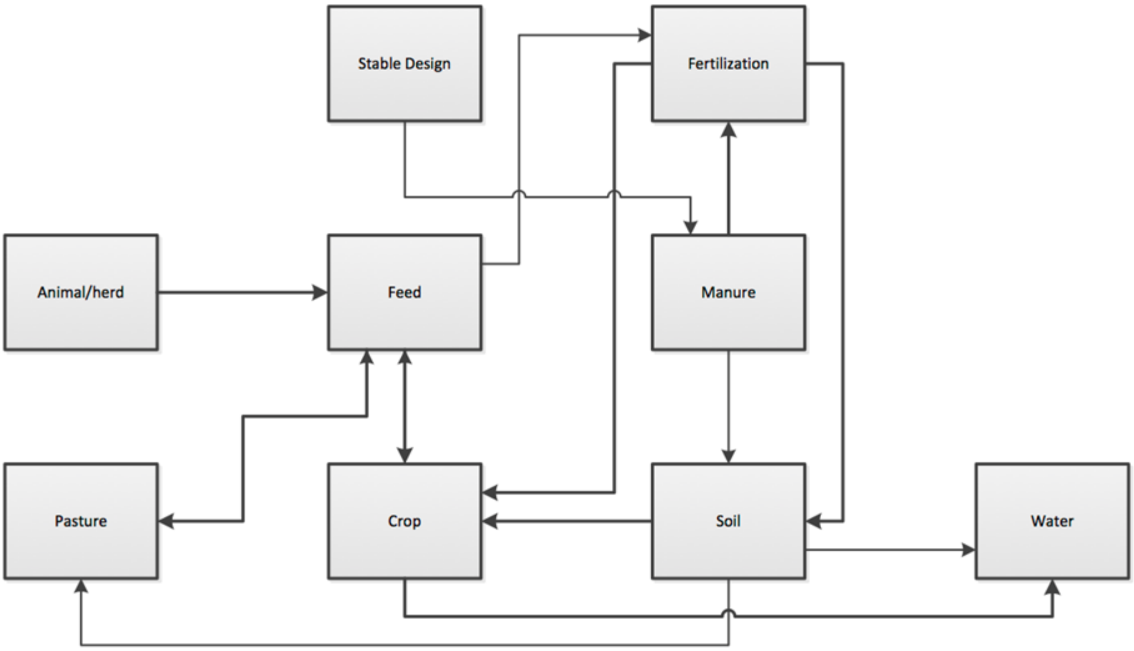


Figure 2 *Clusters of CSA solutions in the CSA Solutions Database.*

The CSA solutions in the database developed in 2016 were allocated to the clusters at two levels: a generic and specific formulation of the solution. This resulted in a categorisation of the CSA solutions at three levels: clusters, generic solutions and specific solutions. The categorisation is represented in a decision tree (see Figure 3).

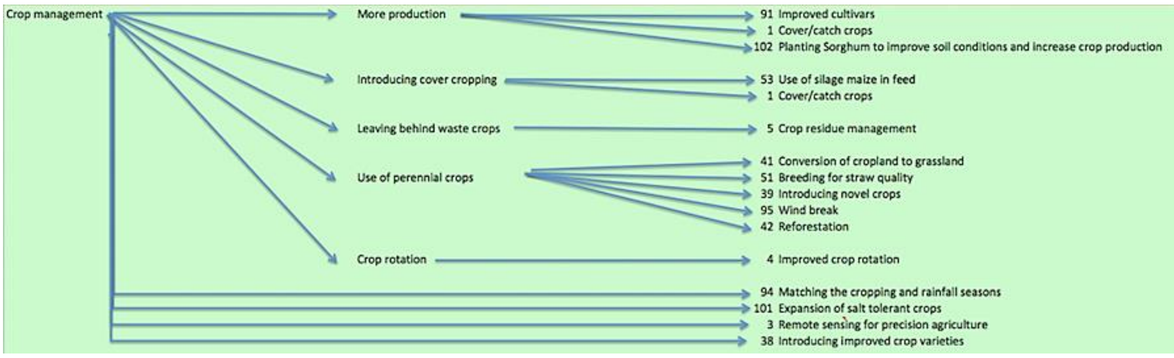


Figure 3 Extract from the CSA Solutions Database for the CSA Cluster Crop management, illustrating the allocation of solutions to clusters.

Selection of 25-35 'best practice' solutions

We invited 10 experts from Wageningen Research to a workshop to select 25-35 'best practice' CSA solutions for dairy farming from the long-list of 100 compiled in 2016. The objective of the workshop was to get to a set of best practice CSA solutions for dairy farming from every cluster.

We used the Delphi method and a questionnaire to elicit the experts' judgement on the CSA solutions. The Delphi method structures a group communication process to deal with a complex problem. In this method, responses from experts are modified on feedback from other experts in subsequent steps.

This is continued until each expert is satisfied with the outcome (Okoli & Pawlowski, 2004; Sun et al. 2015).

The questions presented to the experts included:

1. Fill in the two best climate smart agriculture solutions per cluster for dairy farms. A good solution reduces GHG emissions and/or makes the farm more resilient to climate change, while at the same time maintaining the productivity or profitability.
2. Fill in the effect of the solution on GHG emissions reduction and the cost effectiveness.
3. Give a short argument on why this is the best solution.
4. If you consider more than two solutions per cluster as 'best', include them as well.
5. If you have no knowledge regarding a certain cluster, leave the space open.

We asked the experts to consider the following requirements of the CSA solutions in their judgement:

- The solution must be cost-effective at farm level;
- The solution must have mitigation and/or adaptation potential;
- The solution must have been demonstrated as 'best practice';
- Farmers must be willing to implement the solution in their farming activities.

The experts selected the CSA solutions displayed in Table 1. The selection was discussed with partner South Pole Group, and a final selection was made of 32 CSA solutions for documentation in the CSA Solutions Database.

Table 1 Results from the expert meeting, showing the estimated best CSA solutions per cluster and arguments.

CSA Cluster	CSA Solution	Arguments
Animal management	Increasing productive lifetime of animals	Reduces the total GHG emissions per total product over the animal's lifecycle.
	Prevention, control and eradication of diseases	Keeping the animals healthy will increase production and thus will lead to less GHG emission per unit of product.
Feed management	Roughage quality	By improving the roughage quality the CH4 emissions will be reduced. Production rate will not go down and might even go up. However, it must be considered what the substitute feed will be, since land use change might be involved when growing other crops
	Dietary improvements and adding feed substitutes	Feed substitutes can change fermentation processes in the rumen and influence methane production. Feeding corn, legume silages, starch, soya or brassicas compared to feeding grass silages can reduce CH4 emissions. It is a measure that can be cost effective.
	Precision feeding	Effective option, low risk and cost effective. Controlling for constant quality of feed will reduce CH4 emissions. Is coherent with the milking robot that provides data regarding the production. Based on this data, precision feed can be compiled.
Manure management	Housing and manure handling	In some regions manure is not yet collected and treated as waste or lost directly to the environment. For those regions manure collection is a first step. Housing systems with concrete floors in combination with simple equipment for manure storage prevent run-off of valuable nutrients to the environment, and therewith eutrophication of the environment, and improve hygiene for lactating dairy cows.
	Manure cooling	Cooling of manure-covered surfaces and cooling of slurry will lead to less CH4 emissions because the activity of methanogenic bacteria is reduced under low temperatures.
	Anaerobic digestion	Well known technique, only costs are still too high and subsidies are required. CH4 emissions will reduce with 32-68% and emissions in CO2 equivalents will reduce with 14-59% after storage of digested manure, compared to untreated manure.

	Manure separation	Can reduce CH4 emissions, and offers potential to apply manure more efficiently. Applicable in regions with a manure surplus. Manure separation requires additional measures to improve GHG mitigation, such as covering of the solid/liquid manure and/or anaerobic digestion.
	Addition of acidifiers to slurry	Results in a strong reduction of CH4 emission.
Fertilization	Application method, rate and timing of fertilizer	The solution is fine-tuned for the demands of the crops/pasture. The benefits are reduced losses of nutrients, and improved uptake of nutrients by crops. Proper timing influences the N2O emissions both directly and indirectly. Farmers are willing to undertake this action and the profit will increase.
	Applying manure and compost as fertiliser	Organic fertilisers provide valuable nutrients to increase the SOM content and to enhance soil quality. Applying organic fertilisers on the farm can reduce the need for mineral fertilisers, while also stimulating crop growth and improving crop performance.
Pasture management	Optimal grazing	Grassland with appropriately managed grazing stores more soil C than ungrazed grassland. CH4 emissions may reduce due to less manure storage, but N2O emissions increase from urine patches.
	Legumes and mixtures	Legumes tend to fix N, and for that reason the need for N fertilizer decreases, resulting in decreased N2O emissions. Farmers are willing to reduce the amount of applied fertilizer via biological N-fixation.
Crop & soil management	Reduced tillage	Farmers are willing to change their tillage strategy in order to mitigate climate change, as extra costs are limited. Reduced tillage causes less soil disturbance than conventional tillage and thus the decomposition of organic matter decreases, as do GHG emissions. In the mean time? SOC stocks increase. A disadvantage is that reduced tillage may lead to increased N2O emissions, but the overall effects on GHG emissions in CO2 equivalents are positive (Sikirica et al. 2016).
	Cover crops	Cover crops maintain production levels with only little extra costs. Besides they store soil carbon (Pellerin et al. 2017). Adding a cover crop improves the soil quality, reduces soil erosion, enhances nutrient cycling and the water holding capacity and thus the production might even increase. Winter cover crops will use the available soil N, which results in prevention of nitrate leaching and indirect N2O emissions (Sikirica et al. 2016).
	Improved crop rotation	It is relatively easy to implement, and insight is high. Improved crop rotations can benefit to farm soils by building soil organic matter, enhancing soil fertility and improving the(deep) soil structure, and by helping to replenish nitrogen in the soil, by reducing erosion, and by increasing the water infiltration capacity of the soil.
Water management	Precision irrigation	Research shows that there is a potential improvement in both water use efficiency and crop quality when using precision irrigation.
	Increase groundwater level in peat-meadow to combat peat losses	Avoids carbon losses from peat soils.
Infrastructure	Controlled traffic of machinery	Controlled traffic in farming enables to reduce emissions from soil of N2O (21-45%), CH4 (372-2100%), water runoff (27-62%), direct in-field emissions (23%) and indirect impacts associated with fertiliser, pesticides, seeds and fuel.
	Reduce fossil fuel use by machinery	Reduces CO2 emissions. Farmers are willing to implement this measure.

3.2 CSA Solutions Database

The objectives of the CSA Solutions Database are to:

1. Store information on CSA solutions which is relevant for actors in dairy farming;
2. Provide information to enable an assemblage of CSA solutions based on characteristics of regions, current farm systems and preferences of actors in dairy farming.

For both objectives, the CSA Solutions Database is not directly accessed by users, but functions as the back-bone of the CSA Spatial Solution Finder (). Access to the information on the CSA solutions is through the CSA Spatial Solution Finder (webtool). The structure of the webtool will be explained in chapter 4.

The characteristics of CSA solutions included in the CSA Solutions Database (Table 1) were taken from the online questionnaire for the entry of new CSA solutions developed by South Pole Group and WENR for the CSA Booster in 2015[5], and from the assessment framework for CSA Solutions developed for the CSA Booster as part of task 1.2.6[6].

Table 2 Characteristics of CSA solutions in the CSA Solutions Database.

Characteristic	Unit	Description and comments	Reference
Targeted GHG	CO2, N2O, CH4	Can either be direct or indirect emissions of the greenhouse gas concerned.	
Cost-effectiveness	€/tCO2e	Cannot be defined for all the solutions due to a lack of information. Negative values indicate a profit at the level indicated (farm or larger domain).	Pellerin et al. 2017; Moran et al. 2011
Unitary costs	€/ha/yr	Can also be defined as €/animal/yr or €/tractor/yr.	Pellerin et al. 2017
Training	Needed or not needed	Refers to whether or not a farmer needs training to implement a solution. Disadvantage is that it very much depends on the level of education of the farmer.	
Costs	CAPEX (1 time payment in € for 1 unit): $=0-30k, $$=30-150k, $$$=>150k OPEX (annual costs over 5 years in € for 1 unit): $=0-8k, $$=8-40k, $$$=>40k	Can partly be defined based on the unitary costs. However, it is hard to find literature that explains the source of the costs and thus to distinguish between CAPEX and OPEX. Also, both capital and operational costs depend on the scale of implementation.	South Pole Group (2017)
Co-benefits	Description	Based on benefits found in literature apart from mitigation, adaptation and productivity benefits, e.g. improved soil quality and landscape.	
Climatic applicability	Cold Cool temperate Intermediate temperate Warm temperate Hot All	Based on the annual average temperature. Important for solutions that require a certain climate.	Metzger et al. 2012
Soil type	Sand	Refers to the soil type required for the solution.	

[5] http://csasolutionhub.thesouthpolegroup.com
[6] South Pole Group, 2017. Deliverable 2 for the work plan task CSA Solutions Database and Spatial Solution Finder.

	Clay Peat All		
Farm specialization	Livestock: dairy, beef, pig, sheep, poultry, other Crops: annual, perennial, horticulture	Refers to the farm specialization to which the solution applies	
Barriers	Financial Technological Natural Social/cultural Human	Based on barriers found in literature.	Pronk et al. 2015
Additional concerns	Description	Based on concerns found in literature.	
Impact on productivity	% change compared to standard practice OR a qualitative rating in terms of: Increased productivity Similar productivity Decreased productivity	Dependent on the scientific data available. Option 1: Quantitative indication % change compared to standard practice in kg per unit output of farm product based on literature or case study Option 2: Qualitative indication: Increased productivity Similar productivity Decreased productivity	
Impact on mitigation	% change compared to standard practice OR Increased emissions Similar emissions Decreased emissions	Dependent on the scientific data available. Either expressed in % change or a qualitative indication.	
Impact on adaptation	Increased resilience Similar level Decreased resilience	Resilience against the following physical impacts: -Water scarcity and droughts -Increased frequency and severity of floods and storms -Changing rainfall patterns and increased rainfall intensity -Increased weather extremes and variability -Rising average temperatures -Shifts in seasons -Rising sea level and increased saline intrusion -Changes in pest and disease distribution and prevalence -Loss of biodiversity -Forest fires	Ceres, Oxfam, & Calvert Investments, 2012
Classification	Climate smart or not climate smart	A solution is climate smart if it does not negatively affect productivity and has a certain mitigation and/or adaptation impact. Qualitative judgement based on the three CSA impact variables listed above in the table. A detailed assessment framework to assess the 'climate-smartness' of the solutions was created in the CSA Booster project (ref). This was applied to 5 of the 32 solutions in the CSA Solutions Database.	

In combination with	Description	Indication of solutions that intensify each other with respect to mitigation, adaptation and productivity, or that are required to implement in combination with the solution under consideration in order to achieve CSA impact.	

The information on the 32 CSA solutions in the CSA Solutions Database is currently stored in a Google Spreadsheet[7] (Figure 4). This format was chosen to enable joint work on the entry of information by a team of six specialists from Wageningen Environmental Research and South Pole Group. The information was entered in the period from October to December 2017 from peer-reviewed studies, scientific and technical reports, meta-analyses, reports from the dairy industry and from institutions operating in the dairy sector. A web interface can be built in a later stage of the CSA Booster project to facilitate the online entry of new data on CSA solutions. In the future, all solutions in the database will be assessed by using the CSA Solution Assessment Protocol (CSASAP), a standard operating procedure to help assess CSA impacts as well as scalability.

Layer1: Category	Solution name	Socioeconomic data			
		Targeted GHG direct and indirect	Costs per tCO2e	Unitary costs	Training
Animal Health	Effect of lactation length on GHG emissions	CH4 (60,118)	-€279/tCO2e(60)		needed
Animal Health	impact of subclinical ketosis in dairy cows on GHG emissi	CH4 (119)	negligable	per cow	needed
Animal Health	avoid anaerobic conditions in cubicles, for example by usi	CH4 (111)	4.8-179 mg CH4/m2/hour	€100 per cow per 10 yea	not needed
Feed&Nutrition	improve forage quality: by selection of forage genetic strai	CH4 (52, 135)	n.a.		
Feed&Nutrition	improve forage quality: by harvesting or grazing less matu	CH4 (58)	€57/t CO2e for strategy 'reducing maturity stage c	€10/ha.y or €6/animal.y (	
Feed&Nutrition	increasing harvest maturity of whole-plant corn silage redu	CH4 (107)	negligable		not needed
Feed&Nutrition	Replacing grass silage with maize silage	CH4 (54, 60)	-€14/tCO2e(60)		not needed
Feed&Nutrition	Processing of feed: Mechanical processing of corn (rolling	CH4 (52,53,81), CO2 through rec	-390 €/tCO2e (5)	600-18'000 EUR/unit (82	Needs nutritionist to ac
Feed&Nutrition	Precision feeding at individual animal scale to increase fee	CH4 (134)	n.a.	796 versus 853 kg CO2e	needed
Feed&Nutrition	increase concentrate feeds and starch ratio in mixed and i	CH4 (58)	€2594/t CO2e for supplementation of extruded lin €241/t CO2e for a nitrate concentrate; uncertainty	€357/ha.y or €211/anima €122/ha.y or €72/animal.	
Manure Management	Housing systems with concrete floors (or possibly hard cla	N2O (1), CH4 (34)	1-20€/Kg NH3 (79)	124€-239€ / animal / yea	Needed depending on

Figure 4 Extract from the CSA Solutions Database.

[7] http://bit.ly/2z9E3nF

4 CSA Solutions Finder

The CSA Spatial Solution Finder is a webtool aiming to help farmers, farm advisors, and policy planners find those solutions for climate-smart agriculture that fit farmers, farms and regions, and to provide contextual information for the examples of successful implementations shown on the CSA Booster Open Innovation Platform (www.agrisource.org). The webtool at present focuses on livestock farming for dairy production. However, in the future the scope can be expanded to other agricultural subsectors such as perennial crops or horticulture.

The webtool guides the user in four steps to a first set of CSA solutions, that could be used to change farm management in response to the profile of current greenhouse gas emissions from dairy farming, either in the region or farm of interest. In addition, by means of the map windows the tool enables the user to compare regions (at NUTS-2 level) with regard to the current livestock production system, greenhouse gas emissions, environmental zone and vulnerability to projected limitations on (feed) crop growth from a decrease of precipitation.

The set of CSA Solutions is presented to the user assembled in clusters representing the compartments of dairy farms generally found in Europe: manure, feed, pasture, animals, crops and soil, fertilization and energy. For each CSA solution the user can consult a description and characteristics from the CSA Solutions Database. With the initial set of CSA solutions suggested by the CSA Spatial Solution Finder, the user (farmer, advisor, planner) could undertake a process of consultation and negotiation with other actors in the dairy value chain on which solutions to adopt or to encourage. For further refinement of a package of solutions fitting a specific farm condition, an advisory trajectory is required between farmers, advisors and companies (suppliers or buyers). The options suggested by the CSA Spatial Solution Finder, and the regional patterns related to dairy farming and the environment may guide this process.

The design and navigation steps in the webtool are described below.

4.1 Design

The CSA Spatial Solution Finder (CSA SSF) consists of a website which uses information from four sources to compile a set of CSA solutions fitting to a farm type or region: the CSA Solutions Database, the Cool Farm Tool, information from the user and spatial information (Figure 6).

CSA Solutions Database (CSA SDB)
The CSA Solutions Database provides detailed information on CSA solutions: a short description, cost effectiveness, unitary costs, training needs, applicability with regard to climate, soils and farm specialization, barriers and other concerns, impacts on productivity, mitigation and adaptation, scalability, relations to other CSA solutions and references (Table 2).

In the current version of the CSA Spatial Solution Finder, the CSA Solutions Database is connected via 'loose coupling': the information from the Google Spreadsheet is copied to the database behind the webtool. For future editions, a web interface will be built to enable dynamic entry and update of information in the SDB, which can be shown in the webtool in real time.

Cool Farm Tool (CFT)
The Cool Farm Tool[8] is an online calculator for greenhouse gases, water and biodiversity for farming. The module for greenhouses gases quantifies on-farm greenhouse gas emissions and soil carbon sequestration. CFT provides greenhouse gas emissions (in kg CO2eq or kg per gas) and emissions per

[8] https://coolfarmtool.org/coolfarmtool/

litre or kg of milk for components of dairy farming systems (see Figure 5). The proportions of emissions from components of the farming system are used in the webtool to compile a first set of CSA solutions which address specifically these components. This is done based on relationships between the farm components of the CFT and the clusters of CSA solutions in the CSA Solutions Database (see 3.1) (Table 3).

	CO_2	N_2O	CH_4	Total CO_2eq	Per litre	Per kg FPCM
Direct energy use	0			0	-	-
Enteric fermentation			2747	68670	0.59	0.60
Feed production	21444			21444	0.18	0.19
Grazing				18661	0.16	0.16
Manure management				83	-	-
Off-farm transport	0			0	-	-
Total	40188	0	2747	108858	0.93	0.96

Figure 5 Example output of the Cool Farm Tool. Source: coolfarmtool.org.

Table 3 Relations between CFT Farm component and clusters of CSA solutions in the CSA Spatial Solution Finder. -: cluster not available in the current version of the webtool.

CFT Farm component	Cluster of CSA solutions in webtool
Crop – Land management	Crop & Soil management
Crop – Soil/fertilizer	Fertilization
Crop – Pesticide	-
Crop – Residue management	Crop & Soil management
Crop – Energy & processing	Energy use
Crop – Waste water	-
Crop – Transport	-
Dairy – Energy & processing	Energy use
Dairy – Transport	-
Dairy – Grazing	Pasture management
Dairy – Feed production	Feed & Nutrition
Dairy – Manure management	Manure management
Dairy – Enteric fermentation	Feed & Nutrition + Animal health

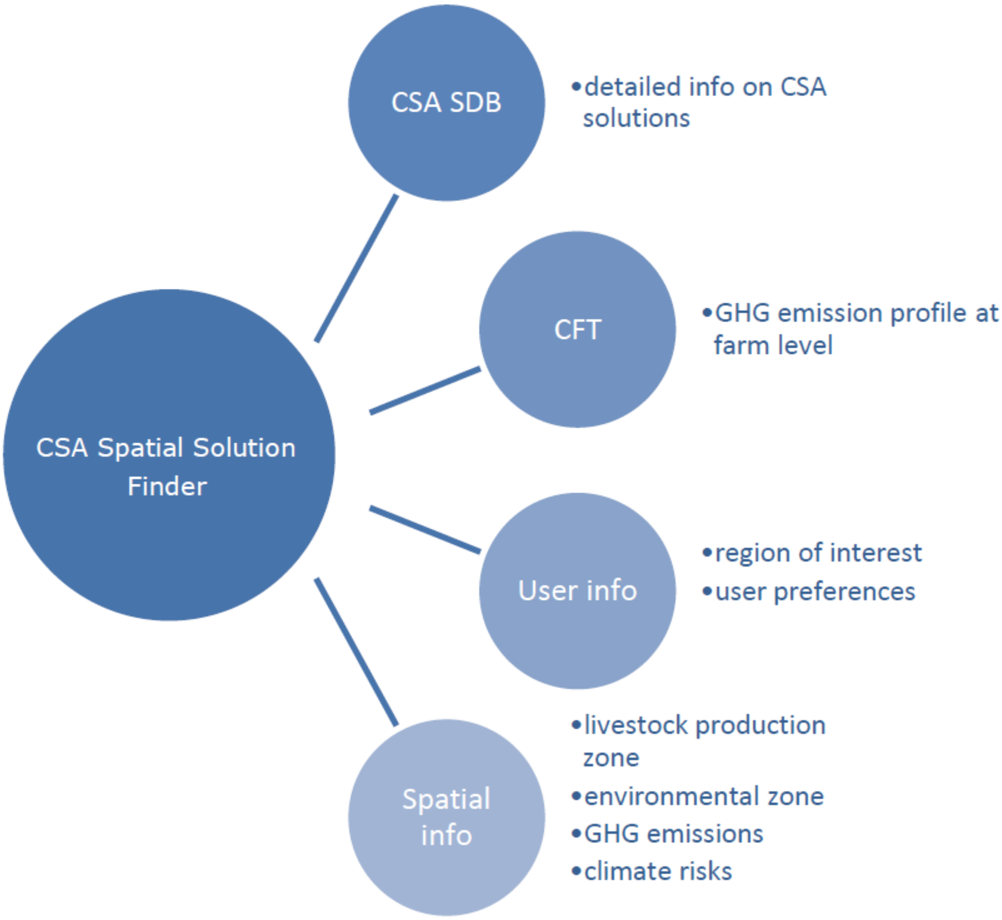


Figure 6 Basic lay-out of the CSA Spatial Solution Finder. CSA SDB: CSA Solutions Database; CFT: Cool Farm Tool.

The Cool Farm Tool was selected as the carbo accounting tool for the farm level because it was developed for European conditions, and because the Cool Farm Alliance is a partner in the CSA Booster Flagship. The COMET farm tool was also considered, but had several disadvantages compared to the Cool Farm Tool:

- COMET farm tool can only be applied to the US; it is not possible to select a location in Europe. To calculate the carbon footprint, spatial data on soil and weather phenomena are included. Since these are different for the US and Europe, the results are less applicable to European farms.
- The results that COMET farm tool provides only include amount of emitted CO2, N2O and CH4. The results do not give an indication of the farm component producing the greenhouse gas.
- The COMET farm tool asks for a lot of input, which is time-consuming.

In the current version of the CSA Spatial Solution Finder the emission profiles from the CFT must be manually by the user. For future editions, a direct connection to the database of the Cool Farm Tool is envisaged.

User information

The information required from the user of the webtool for presenting a first set of options for CSA solutions consists of the region where the farm of interest is located, and of his/her preferences with regard to farm management.

Region
The region determines the suitability of CSA solutions based on the natural conditions (climate, soils, relief), structural conditions (land, capital and labour), organisational conditions (structure of the agricultural sectors), and financial conditions (access to credit and hedging of financial risk)[9].

Information on conditions of the region in the current version of the SSF is obtained from the map of livestock production zones from INRA[3] (direct entry upon selection of a region by the user), and from the map of environmental zones of Europe[10] (to be queried by the user).

The typology of livestock production zones for Europe is based on the animal density and on the percentage of permanent grassland relative to the total utilizable agricultural area. It distinguishes four main categories of regions of livestock production in Europe[3]:

1. Areas with high animal densities and minimal permanent grassland, accounting for 30% of the European livestock herd and 11% of utilizable agricultural area in Europe.
2. Grassland areas, where grassland productivity determines both levels of production and strategies of product differentiation (35% of the European herd on 33% of utilizable agricultural area). Animal densities in these areas can be variable. This class has three sub-classes.
3. Areas with both crops and livestock, including a wide range of dynamics from complementary crop-and-livestock systems to situations where livestock production is being pushed out in favour of expanded crop production (27% of the European herd and 32% of utilizable agricultural land).
4. Areas with less livestock and grassland than the other three categories.

The criteria for the classification were set by experts, and are given in Table 6.

Table 4 Definition of European livestock production zones[3]. UAA: utilizable agricultural area; LU: livestock units; STH: grassland area.

Livestock production zone	Animal density	Land use
Low-grassland areas with high livestock densities	LU/UAA > 1,2	STH/UAA < 0,4
Grassland-dominant areas with high livestock densities	LU/UAA > 1,2	STH/UAA > 0,4
Grassland-dominant areas with average livestock densities	0,4 < LU/UAA < 1,2	STH/UAA > 0,4
Grassland-dominant areas with low livestock densities	LU/UAA < 0,4	STH/UAA > 0,4
Both crop and livestock production	0,4 < LU/UAA < 1,2	STH/UAA < 0,4
Low-grassland areas with low livestock densities	LU/UAA < 0,4	STH/UAA < 0,4

The recommendation of CSA solutions for each livestock production zone is based on an expert judgement on how well CSA solutions for specific farm components (represented by the CSA clusters, see 3.1) are expected to address productivity, mitigation and adaptation in the livestock production zones (

[9] J. Hercule, V. Chatellier, L. Piet, B. Dumont, M. Benoit, L. Delaby, C. Donnars, I. Savini, P. Dupraz. 2017. Une typologie pour représenter la diversité des territoires d'élevage en Europe. INRA Prod. Anim., 2017, 30 (4), 285-302.
[10] Metzger, M. J., Shkaruba, A. D., Jongman, R. H. G., & Bunce, R. G. H. (2012). Descriptions of the European environmental zones and strata (No. 2281). Alterra, Wageningen Research.

Table 5).

Table 5 Connection between CSA Clusters (a-h) and livestock production zone. Green: best option; Blue: good option; Purple: plausible option; Red: not a good option

	a. Animal health	b. Feed & Nutrition	c. Manure management	d. Fertilization	e. Pasture management	f. Crop & soil management	g. Energy use	Description and rationale
1 Low grassland area + high livestock density	2	1	3			0		10% of the UAA of the EU 29% of total livestock units, mainly pigs, chicken and dairy cows. Zones with highest livestock density (2.17 UGB/ha SAU). Denmark-Germany-Bretagne-Pays de la Loire-Catalogne-Lombardie-western Poland. Livestock farming that is not land-based; focus is on reducing GHG emissions from animals and manure handling, not on land management.
2 Grassland dominated + high livestock density	3		1		2			Not so extended in Europe: 7% of the UAA, 14% of total livestock units. Lower livestock density than zone 1 (1.66 UGB/ha SAU), but still above the average for Europe (0.78 UGB/ha SAU). Regions focussed on dairy farming and breeding. In plains and piedmonts with high precipitation and fertile soils, therefore high feedstock production, **low** purchase of feed grains to supplement fodder. E.g. Netherlands, southern Ireland, Bayern, Galicia. Focus is on reducing GHG emissions from grassland and manure handling; on animal health because of the high livestock density.
3 Grassland dominated + average livestock density		2			1			18% of the UAA in the EU 18% of the total livestock units in the EU Sheep and goats, fewer cows than zones 1 and 2 (25%) Mountainous areas of middle and high altitude with grazing, e.g. Massif central, Austria, Carpathians. Focus is on maintaining pasture land in providing feed and sink capacity for C. No complicated movements with feedstock, fertilizer or manure.
4 Grassland dominated + low livestock density				2	1			Zone covering only a small UAA in EU (6%) and small part of livestock units (2%). In e.g. northern Scotland, southern Portugal, Alpes de Haute Provence. Large proportion of grazing animals among the livestock, small and large. Less productive grassland,sometimes classified as areas important for maintaining biodiversity (e.g. the Mont Ventoux, Grosse Walsertal, Tatras mountains). Focus is on maintaining the productivity and sink capacity of grassland. Focus is on crop and soil management.

	a. Animal health	b. Feed & Nutrition	c. Manure management	d. Fertilization	e. Pasture management	f. Crop & soil management	g. Energy use	Description and rationale
5 Crop & livestock production		3		2		1		Grazing land 30% of the total agricultural area (vs 70% in the grassland-dominated areas), covering 25% of total livestock units. Grazing land (grassland permanent and temporary, rangeland) covers 30% of the UAA, compared to 44% in the zones with high livestock density, and 70% in the grassland-dominated zones. Half of livestock is grazing animals, half is grain consuming. Most diverse zone in terms of production systems and farm types. Ex Poland and other eastern European countries. Zone includes many different farnm types, specialized in either large-scale arable cropping or farms specialized in livestock farming. Focus is on balancing crop and feedstock production and livestock production in the regions, therefore a mixed palette of solutions is returned.
6 Low grassland area + low livestock density	0			2		1		24% of the UAA in the EU 8% of total livestock units in the EU Limited role of livestock farming, or even absent, of little importance in both areal coverage and agricultural production. Zones of arable annual cropping (Paris basin) and perennial cropping, e.g. vineyards (Bordeaux, Champagne, Languedoc, Toscane), olives and fruit (Andalusia, southern Italy, Baltic states, Bulgaria, Greece). Focus is on reducing GHG emissions and improving the sink capacity of cropped land.

Preferences
The farmer, advisor or policy planner consulting the webtool may have preferences on CSA solutions for the farm, farm type or region of interest, like 'easily implementable, without much training', 'with low operational cost' or 'with a high cost effectiveness, whatever the capital cost' or 'highly scalable to other regions'. These preferences may be used to obtain a limited set of tailor-made solutions for a specific user. This functionality is not yet operational in the webtool, but the method was developed in 2017 and is ready to implement in 2018.

The method adheres scores to each solution based on the specific situation of the user. The scores range from 0 to 100. A score of 0 for a specific use case means a wrong or irrelevant solution, a score of 100 indicates a perfect solution. The solutions with the highest scores are presented in a dynamic table ordered by score (best solutions first). Solutions with relatively low scores are omitted. Users may not only want to consider the solution with the highest score, but also solutions with slightly lower scores. Indeed, due to very specific local circumstances (e.g., education, eagerness to invest), solutions with slightly lower scores may potentially be more attractive than the solution with the highest score.

Scores will be assigned to each solution by means of a simple broker system. First, the website asks the user a limited number of relevant questions about his farm situation (e.g., eagerness to invest, need for training, main soil types). His answers are matched with answers earlier provided by experts. For instance, if a user indicates that his farmland predominantly consists of clay, then solutions that according to the experts are more relevant for sandy areas will get a lower score. Also, if a user indicates that he is reluctant to invest, then expensive solutions will get lower scores than cheaper solutions.

A farmer may also wish to test what happens to the scores if he gives a different answers. For instance, he might investigate how the ranking of solutions changes if he is willing to follow a training course or when he can find additional funding to invest.

The broker system described above is not new. A similar approach has also been successfully applied by http://mapmakersguide.org. This is a webtool for matching interpolation methods to interpolation questions. See also http://edepot.wur.nl/276343 for a technical background.

Spatial information

The spatial information information provided in the webtool aims to provide a spatial context to inform the selection of options for CSA solutions. This is not only information on the region of interest, as described under 'user information', but also on neighbouring regions and other regions in Europe. For example, a map of current greenhouse gas emissions from agriculture could inform a policy planner at the European Commission on which regions have a potential to reduce these emissions. By clicking on a specific region, a farm advisor gets information on the average emission profile for that region, which could serve as a benchmark for farms in the region.

In the current version of the SSF, the following spatial information layers are implemented:

- The Open Street Map for topographical reference;
- The map of livestock production zones in Europe[3]. The typology is based on the animal density and on the percentage of permanent grassland relative to the total utilizable agricultural area. It distinguishes four main categories of regions of livestock production in Europe:
    5. Areas with high animal densities and minimal permanent grassland, accounting for 30% of the European livestock herd and 11% of utilizable agricultural area in Europe.
    6. Grassland areas, where grassland productivity determines both levels of production and strategies of product differentiation (35% of the European herd on 33% of utilizable agricultural area). Animal densities in these areas can be variable. This class has three sub-classes.

7. Areas with both crops and livestock, including a wide range of dynamics from complementary crop-and-livestock systems to situations where livestock production is being pushed out in favour of expanded crop production (27% of the European herd and 32% of utilizable agricultural land).
8. Areas with less livestock and grassland than the other three categories.

The criteria for the classification were set by experts, and are given in Table 6.

Table 6 Definition of European livestock production zones[3]. UAA: utilizable agricultural area; LU: livestock units; STH: grassland area.

Livestock production zone	Animal density	Land use
Low-grassland areas with high livestock densities	LU/UAA > 1,2	STH/UAA < 0,4
Grassland-dominant areas with high livestock densities	LU/UAA > 1,2	STH/UAA > 0,4
Grassland-dominant areas with average livestock densities	0,4 < LU/UAA < 1,2	STH/UAA > 0,4
Grassland-dominant areas with low livestock densities	LU/UAA < 0,4	STH/UAA > 0,4
Both crop and livestock production	0,4 < LU/UAA < 1,2	STH/UAA < 0,4
Low-grassland areas with low livestock densities	LU/UAA < 0,4	STH/UAA < 0,4

- The map of environmental zones of Europe[11]. This map is based on variables of climate, geomorphology, oceanicity and northing. It can be used to determine the applicability of CSA solutions given the conditions of climate (e.g. the annual temperature sum) and geomorphology (e.g. slope angle).
- Maps of greenhouse gas emissions from agriculture in Europe. These maps are based on simulations with the MITERRA-Europe model for the year 2010[12]. The following specific maps are available: CH4 emissions from enteric fermentation and from manure and manure storage, total CH4 and total GHG emissions from agriculture. Examples of how these maps could be used: the emission maps show which regions have relatively high emissions from manure handling and could benefit from solutions for that compartment of dairy farming systems. The ratio of CH4 emissions from enteric fermentation (90% from cattle) to CH4 emissions from manure and manure storage (also from pig, chicken) shows where measures acting on cows (animal, feed) could be beneficial for CSA impact.
- Maps of projected loss in crop yield due to water limitations under scenarios of future climate. These can be used to explore in which regions the production of grass and other feed crops will be constrained by climate change. For these regions, CSA solutions with adaptation impact should be considered.

4.2 Navigation steps in the webtool

The CSA Spatial Solution Finder is accessed at http://www.csaspatialsolutionfinder.org/. Navigation steps 1-4 of the original design (Figure 1) are currently implemented.

[11] Metzger, M. J., Shkaruba, A. D., Jongman, R. H. G., & Bunce, R. G. H. (2012). Descriptions of the European environmental zones and strata (No. 2281). Alterra, Wageningen Research.

[12] Velthof, G.L., Oudendag, D., Witzke, H.P., Asman, W.A.H., Klimont, Z., Oenema, O., 2009. Integrated assessment of nitrogen emissions from agriculture in EU-27 using MITERRA-EUROPE. J. Environ. Qual. 38, 402-417.
Lesschen, J.P., Van den Berg, M., Westhoek, H.J., Witzke, H.P., Oenema, O. 2011. Greenhouse gas emission profiles of European livestock sectors. Animal Feed Science & Technology, 166-167: 16-28.
Westhoek, H., Lesschen, J.P., Rood, T., Wagner, S., De Marco, A. Murphy-Bokern, D., Leip, A., van Grinsven, H., Sutton, M.A., Oenema, O. 2014. Food choices, health and environment: effects of cutting Europe's meat and dairy intake. Global Environmental Change, 26: 196-205.

1. Where is your farm located?

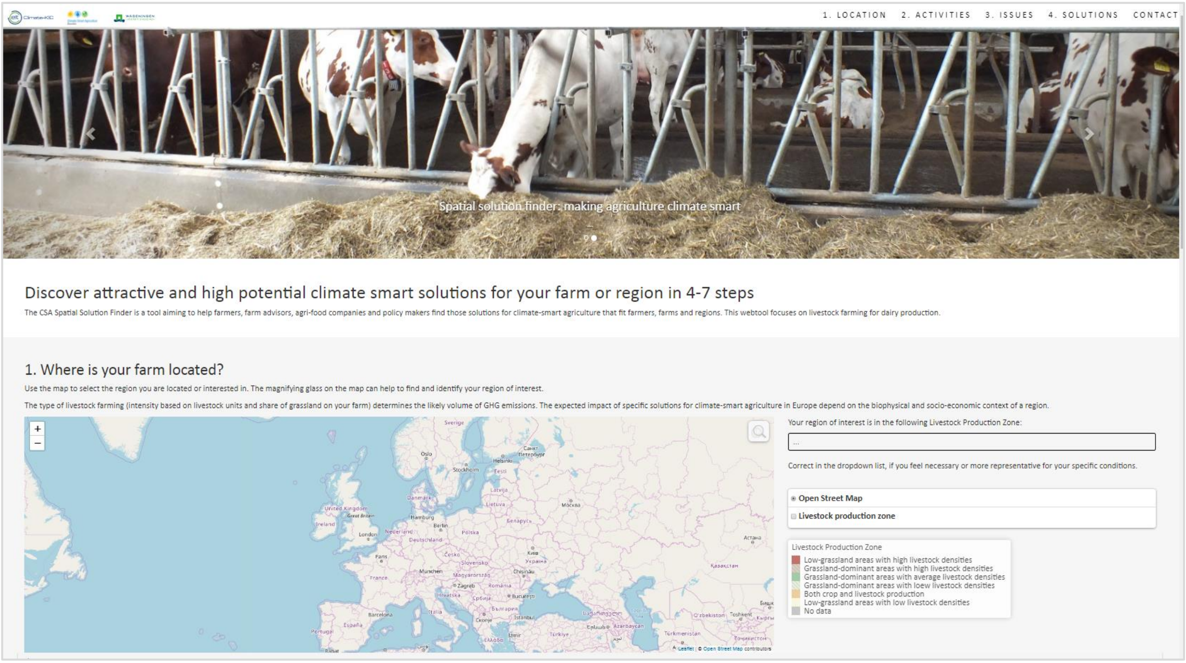


Figure 7 Screen shot of the CSA Spatial Solution Finder: navigation step 1.

In this step the user is asked to select the region of interest. The selection of a region is necessary for a first indication of CSA solutions, because the expected impact of specific solutions for climate-smart agriculture in Europe depend on the biophysical and socio-economic context of a region. On clicking a region, the map will zoom to the selected region.

The map layer with the livestock production zones is shown in the map window to give the user a first impression of the type of livestock farming (intensity based on livestock units and share of grassland on the farm) in the region. This determines the likely volume of GHG emissions. The user is asked to correct the livestock production system in the dropdown list, in case another type is more representative for his specific conditions (navigation step 2a).

2b. Do you have an indication on your greenhouse gas emissions?

This navigation step allows the user to enter quantitative greenhouse gas emissions for different components of the farm system considered. This information is used to select those solutions from the CSA Solution Database that fit the regional and local farming conditions. If the user does not have an application of the Cool Farm Tool but would like to create one, he is referred to the website of the Cool Farm Tool (Figure 8). In the current version of the webtool, the emission data from the Cool Farm Tool must be entered manually. An automated connection to the Cool Farm Tool database is envisaged for future editions.

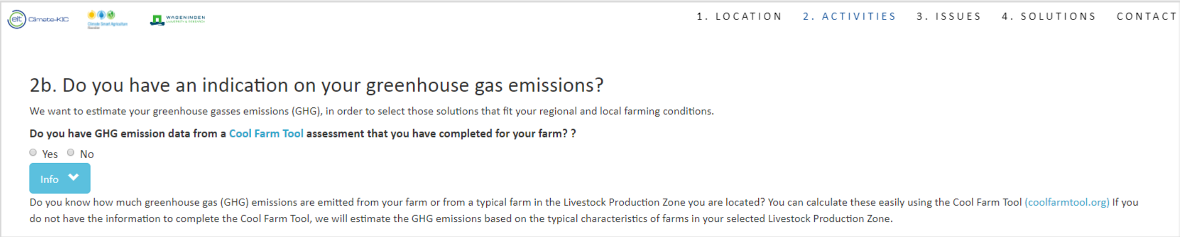


Figure 8 Screen shot of the CSA Spatial Solution Finder: navigation step 2b.

In the current version of the CSA Spatial Solution Finder, the CSA solutions in the database are selected for the three farm components with the highest greenhouse gas emissions. In future editions of the webtool, more advanced selection algorithms can be implemented, e.g. returning the solutions corresponding to the farm component(s) producing at least 50% of the greenhouse gas emissions of the farm. The selection can be subsequently refined based on the user preferences in the module with the broker system described in the previous section.

An example of the entry of a CFT emission profile is shown below for a farm on a sandy soil in the eastern part of The Netherlands. The farm has 15 milk cows, a total milk production of 117.000 l, and 9.3 ha of cropland and grassland. The farm produces 112.009 kg of CO2eq greenhouse gas emissions from the farm components for milk production, which represents 82% of the GHG emissions from the farm (the remaining 18% coming from maize production). The carbon footprint of the farm is 1.16 CO2-eq/kg of milk, below the average for The Netherlands of 1.25 CO2-eq/kg of milk[13]. The example will be used to illustrate the next navigation steps in the webtool.

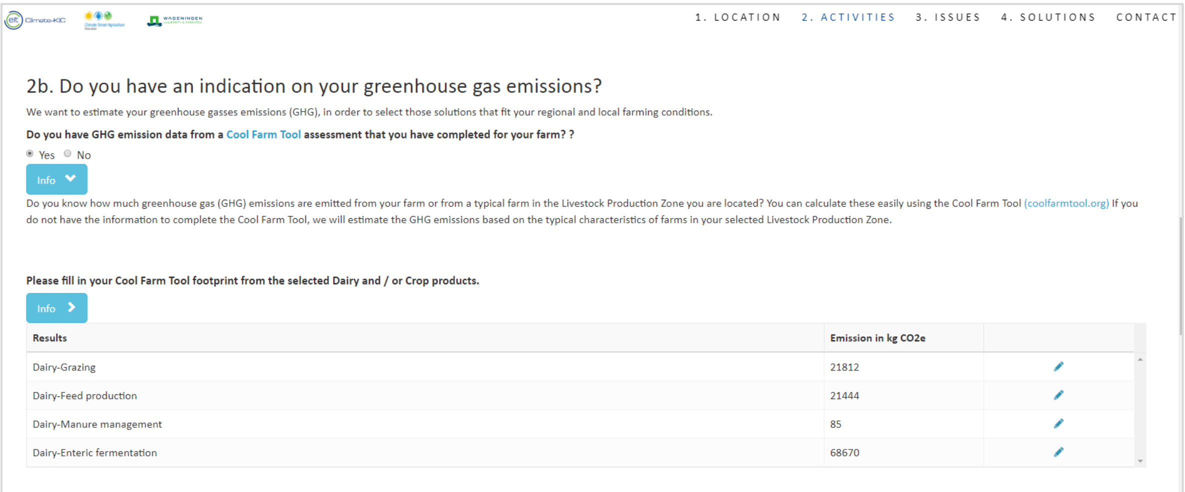
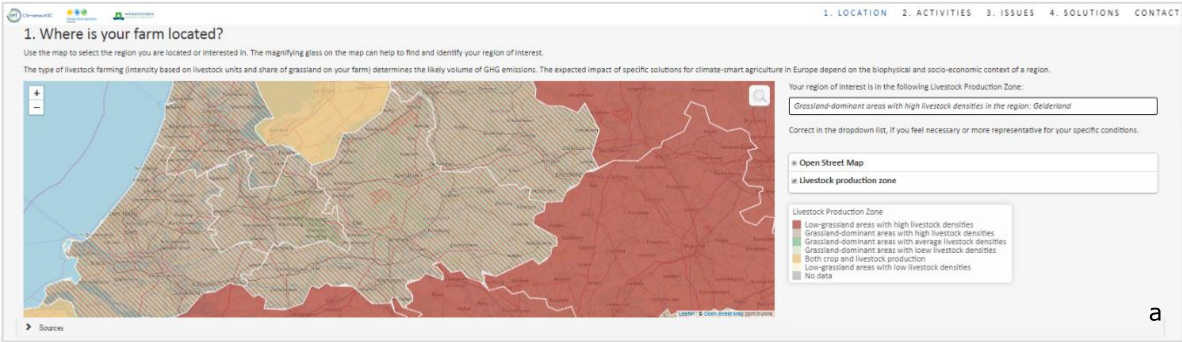


Figure 9 Screen shot of the CSA Spatial Solution Finder: navigation step 2b with an example of a GHG emission profile.

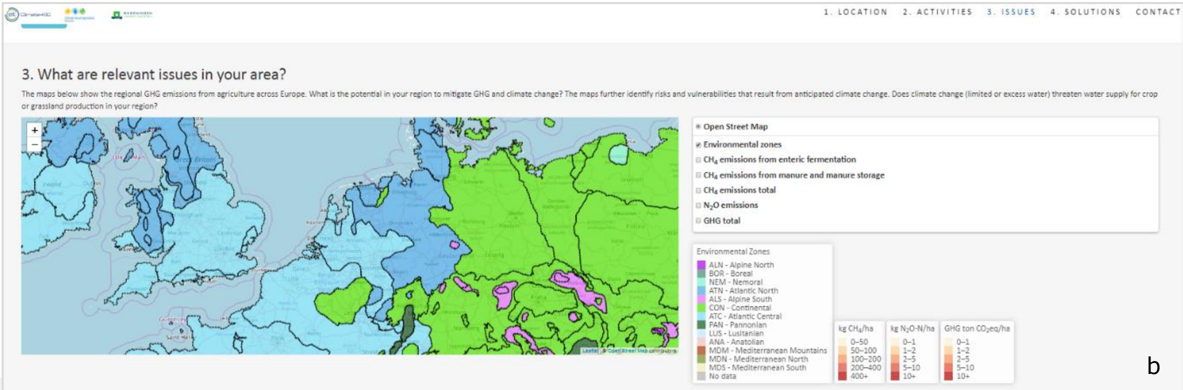
3. What are relevant issues in your area?

In navigation step 3 of the webtool, the user can explore the regional greenhouse gas emissions from agriculture across Europe, to answer questions as given in Figure 11. The answers to questions b and d provide at the same time benchmark values at regional level, to which the performance of individual farms can be compared.

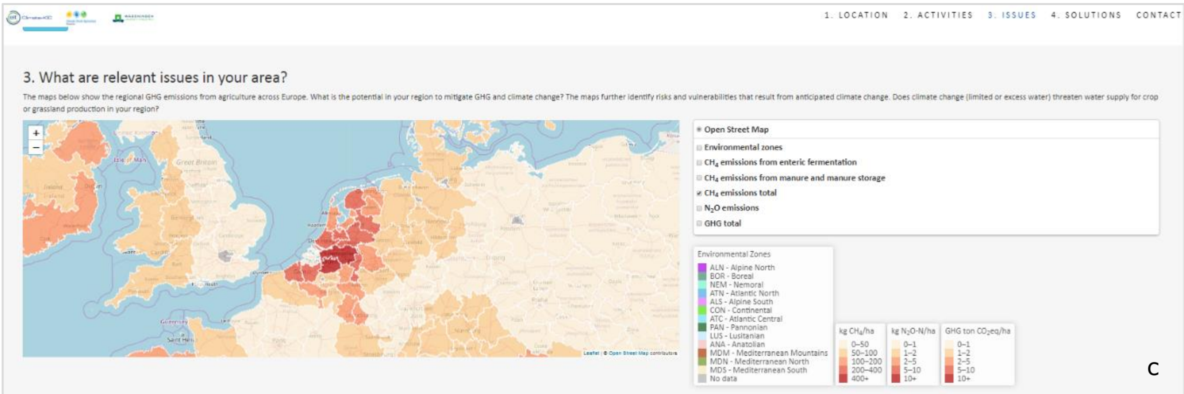
[13] Jan Peter Lesschen, expert on climate change mitigation in agriculture at Wageningen Environmental Research, pers. comm.



The selected region for the example is the province of Gelderland in The Netherlands. The livestock production zone typology is 'Grassland-dominant areas with high livestock densities'.



The selected region for the example is located in the Atlantic Central environmental zone (ATC). This an area with moderate climate where the average winter temperature does not go far below 0°C and the average summer temperatures are relatively low. This is a main agricultural production zone in EU-27.



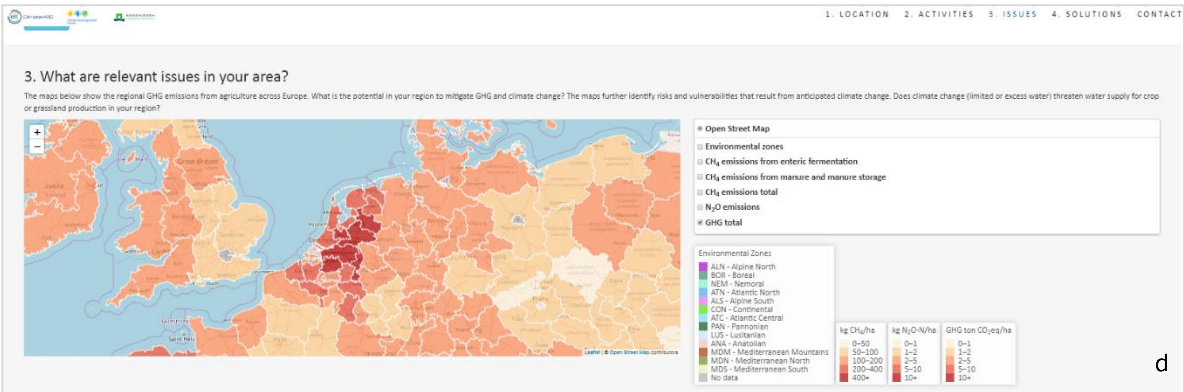


Figure 10 Screen shots of the CSA Spatial Solution Finder: navigation step 3. a: the example region selected in step 1; b: environmental zone; c-d: greenhouse gas emission maps for the region and surrounding regions.

a. 'What do the biophysical conditions of the region tell about the farming system in your region?'	The farming system probably does not suffer much from water shortage, heat and frost. The environmental zone is important for agricultural production in the EU-27. Therefore it is worth investing in CSA solutions.
b. 'What is the potential in your region to mitigate GHG and climate change?'	The potential is high: the region has high GHG emissions from agriculture (>10 ton CO2eq/ha, compared to 4.4 ton CO2eq/ha for The Netherlands*, and corresponding to 16% of the national GHG emissions from agriculture**).
c. 'How does your region compare to other regions in Europe with regard to greenhouse gas emissions from agriculture?'	The emissions of CH4 and N2O are high compared to other regions in Europe.
d. 'Which are the average values of the emissions of different greenhouse gases coming from agriculture in your region annually?'	CH4 emissions from enteric fermentation: >400 kg CH4/ha; from manure and manure storage: 200-400 kg CH4/ha; 5-10 kg N2O-N/ha; total GHG emissions: >10 ton CO2eq/ha.
e. 'Which are important sources in agricultural practice of the emissions in your region?'	Enteric fermentation and manure handling and storage are important sources of GHG emissions in the region. CH4 emissions from enteric fermentation are for 90% produced by cows. The proportion of CH4 from enteric fermentation to total CH4 emissions is indicative of the potential of CSA solutions for dairy farming. This proportion is high for the region (0.65).

*: based on 18.4 Mton GHG emissions in CO2eq from agriculture in The Netherlands in 2016 (National Inventory Report 2016) (in: Lesschen and Kuikman, 2016).

**: CLM, 2016. Landbouw en klimaatverandering in Gelderland. Publication CLM-922. 27 pp. http://edepot.wur.nl/406775

Figure 11 Questions to be answered with information from step 3 of the webtool: 'What are relevant issues in your area?'.

4. Potential solutions

In step 4, the webtool will present a list of options for CSA solutions corresponding to the selected region in step 1 and/or the GHG emission profile from the Cool Farm Tool entered in step 2b. The solutions returned in the example are from the clusters 'manure management', 'feed and nutrition' and 'pasture management', since the example farm had relatively high GHG emissions in the farm components 'grazing', 'feed production' and 'enteric fermentation'.

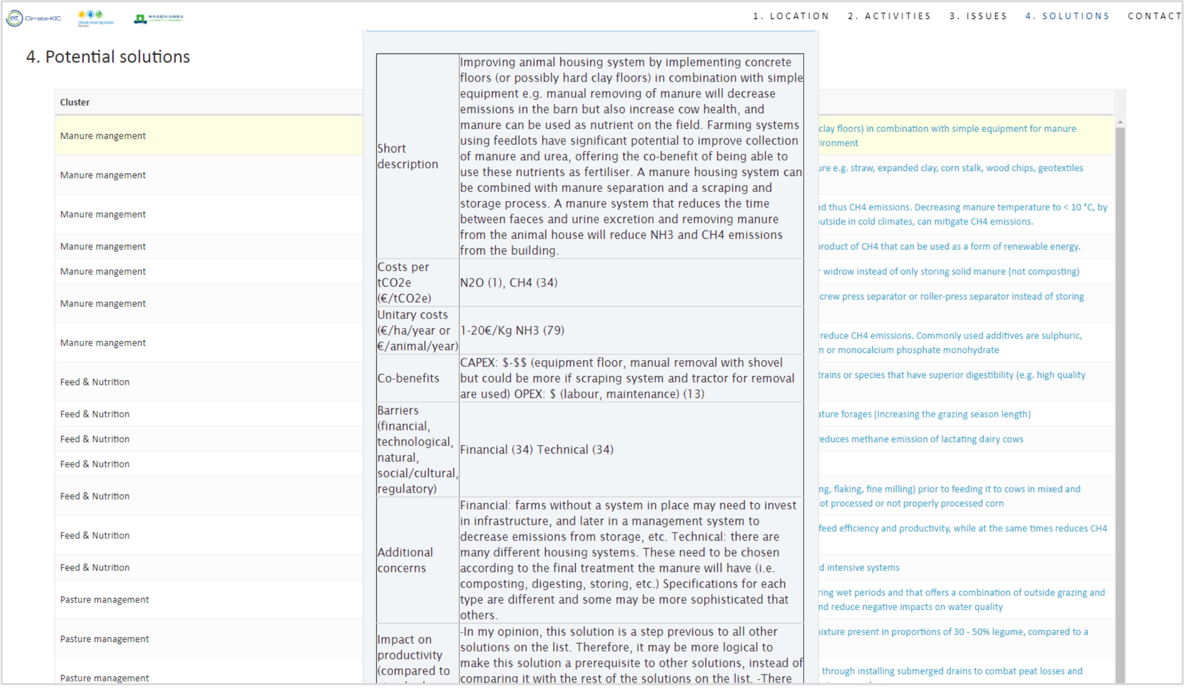


Figure 12 Screen shots of the CSA Spatial Solution Finder: navigation step 4.

By clicking on the description of a solution in the table, detailed information from the CSA solutions Database is shown in a separate window. The user can browse the list of options and retrieve information from the solutions he is interested in. The selection of which solutions to explore further may be guided by the exploration of the GHG emission maps and maps of environmental conditions in step 3. The solutions of interest may be taken into further consultation and exploration in other processes of the CSA Booster, for example those organised by the CSA Booster Regional Hubs or by the CSA Matchmaker.

5 Conclusions and outlook

The CSA Spatial Solution Finder and Solutions Database were developed in 2017 as online tools for the CSA Booster program, intended to be used in activities of the program to support advisors, farmers and policy planners in finding CSA solutions that fit specific sectoral, spatial and regional conditions. The tools consist of a database with 16 characteristics of 32 CSA solutions and a website leading to a first set of options based on spatial contextual information of a region and/or the specification of a GHG emission profile at farm level. The versions presented in this report are preliminary versions focussed on the dairy sector, covering navigation steps 1-4 from the design, in accordance with the work plan for the CSA Booster program of 2017. The webtools need further elaboration on several aspects outlined below.

- **Combinations of CSA solutions:** CSA solutions can be designed in many variants and combinations in a farm or region, and the outcome of each variant and combination depends on the initial situation of the farm management. The CSA Solutions Database carries information on with which other solutions a CSA solution could be combined, but not on quantitative impacts of the combinations, since there is little evidence from literature and practice on the CSA impact of packages of solutions. This could be addressed in further editions of the webtools by mining data from demonstration farms (both input, on the farm structure and measures applied, and output, on the CSA impacts and other outcomes registered in the SDB), e.g. the farms registered in the database of the Cool Farm Tool, and from implementation projects documented in the Open Innovation Platform or guided by the CSA Booster Matchmaking Service and the CSA Booster Regional Hubs. This requires a process of negotiation with the private actors with ownership rights on the data on modalities of access, usage and publishing of the demonstration examples. This process should be coordinated at the management level of the CSA Booster Flagship.

- **Recommending CSA solutions from a broader perspective:** the CSA Spatial Solution Finder recommends CSA solutions from CSA Clusters corresponding to those components of the farm which produce the highest greenhouse gas emissions. For dairy farms, these source farm components are generally manure and fertilization management and enteric fermentation (Lesschen et al. 2011). As a result, solutions for farm components producing lower emissions are not shown to the user. However, these CSA solutions could still be attractive to actors in dairy farming, for instance because they can be implemented without much effort and cost (‘low-hanging fruit’), and in combination with other solutions still contribute to climate-smart agriculture, although the impact of the individual solution with respect to the three CSA indicators may be smaller. The webtools should be improved to also recommend such solutions in combinations of tailor-made sets for specific users by implementing the broker system described in this report. This module is part of navigation steps 5 and 6 of the CSA Spatial Solution Finder (Figure 1), which are planned to be developed in 2018.

- **Connection to farm databases:** a connection to farm databases would enable to base recommendations for CSA solutions by the webtools directly on the structure and current management practices of the farm and the corresponding actual GHG emission profile. In the current version of the CSA Spatial Solution Finder a user having a CFT application must enter the emission profile data manually. An automated connection would allow to retrieve the farm information automatically, upon approval of the user. A direct coupling to the Cool Farm Tool database requires a negotiation process with the Cool Farm Tool Alliance as also recommended under the first bullet. Apart from the Cool Farm Tool, other farm management tools may be considered for automated connections to the CSA Spatial Solution Finder, like the Farm Carbon Calculator and the COMET farm tool, or the tools used by farmers in the regional hubs of the CSA Booster (e.g. the 'Kringloopwijzer' or 'CropVision' in the Dutch hub, and CAP2ER in the French Regional Hub).

- **Develop a strategy on data sources:** apart from farm databases, other data sources could be used to complement the information stored in the CSA Solutions Database, also for other agricultural subsectors e.g. livestock, crop, and aquaculture. Databases are sometimes offered as open source (e.g. FAO database) or require a subscription against a fee (e.g. Ecoinvent). Examples of relevant data sources are: FAOSTAT, the IPCC National Inventory Registries, the Ecoinvent database, GHG Protocol datasets, Markit Environmental Registry, the farm accountancy and farm accounting and survey databases of Eurostat (FADN and FSS), or national statistical databases.

- **Look into automated data integration:** A process should be developed for automated data integration of datasets from relevant data sources or prepared research data by the CSAb staff into the CSA solutions database. This enables fast and larger scale data feeding as well as fast and regular updates.

- **Advanced use of spatial information:**

  More spatial information layers
  the series of maps of 'relevant issues' for climate-smart agriculture presented in navigation step 3 (currently of GHG emissions from agriculture and water limitations for crop growth) could be extended with maps of threats from climate change, pointing to a need for adaptation, e.g. projected changes in frequency and intensity of droughts and flooding, rainfall patterns, extreme weather events, temperatures, shifts in seasons. Maps of opportunities for CSA could be added, e.g. of favourable policy arrangements (subsidies, provisions in Regional Development plans) or market conditions (e.g. regions of investment, like the AgriFoodCapital Region in The Netherlands, maps of competitiveness of regions). A connection is foreseen for 2018 to the information on locations of actors (farms, institutions, business) and pilot projects on the Open Innovation Platform[14].

  Spatially driven selection of solutions using variables from the CSA Solutions Database
  Spatially explicit variables in the CSA Solutions Database could be used to further refine the selection of CSA Solutions resulting from steps 1 and 2 of the navigation, through a spatial query algorithm in the CSA Spatial Solution Finder. The variables with a spatial dimension in the current version of the SDB include climatic applicability, soil type and farm specialization (Table 2).

  The maps currently shown as images (on water limitations for crop growth) should be included in a form allowing overlay with other map layers, panning and zooming.

- **Refine the approach to cost evaluation:** To evaluate the costs of implementation of each solution we developed a scale in order to make the solutions comparable as follows:
  a. Capital Expenditure CAPEX (One-time payment per unit in EUR; unit can be farm, animal, hectare, or kg product output): $ = 0-30k; $$ = 30-150k; $$$ = >150k
  b. Operational Expenditure OPEX (annually over five years in EUR for 1 unit; unit can be farm, animal, hectare, or kg product output): $ = 0-8k; $$ = 8-40k; $$$ = >40k

  These categories could be broken down to smaller categories as unit prices can be very small and cost estimates could be more detailed by interviewing technology and agriculture experts.

- **Develop an approach for benefit calculation**: Benefits of solutions both tangible and intangible need to be better defined and made comparable. At the moment the benefits are listed in descriptive text format e.g. cost reduced, less polluted air. An approach of how to translate benefits into a comparable parameter e.g. Euro value, hours saved, etc. needs to be established. By comparing costs and benefits on a per-unit level using monetary values, the financial net gain, neutrality or financial net loss per solution can be better evaluated. In a

[14] https://www.agrisource.org/en/2_2/the-map.html

next step, a detailed approach should be defined, possibly using ecosystem service accounting standards.

- **Organize the quality management of database:** A team of topical experts should review the data provided for each specific solution on a regular basis to ensure quality of data and source. Also, regular updates should be conducted (e.g. once a year), so that indicated values in the database stay up-to-date.

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