Towards climate-smart sustainable management of agricultural soils

Deliverable 2.12
Inventory of the use of models for accounting and policy support (soil quality and soil carbon)

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AUTHORS:	A. Astover, J. Escuer-Gatius, A. Don
CONTRIBUTORS:	Armolaitis, K. (LT); Astover, A. (EE); Barančíková, G. (SK); Don, A. (DE); Bolinder, M. (SE); Cornu, S. (FR); De Boever, M. (Flanders, BE); Farina, R. (IT); Foldal, C., Jandl, R. Kasper, M. (AT); Fornara, D. (UK); Govednik, A., Mihelič, R., Vrščaj, B. (SL); Huyghebaert, B. (Wallonia, BE); Kasparinskis, R. (LV); Keel, S.G. (CH); László, P. (HU); Lehtonen, A. (FI); Madenoğlu, S. (TR); Maria da Conceição, G. (PT); (SL); Moni, C. (NO); O'Sullivan, L., Wall, D., Lanigan, G. (IE); Sánchez Gimeno, B. (ES); Taghizadeh-Toosi, A. (DK).
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ABSTRACT

This report presents a picture of the inventory of the different models accounting and monitoring soil quality and soil carbon stocks used in 21 different countries in Europe, and especially for the reporting of greenhouse gas (GHG) emissions to the UNFCCC (UNFCCC, 2020). The report synthesizes the information collected regarding the use of these models both at national and farm scale, as well as information of other models for soil quality monitoring, by different actors (policy making, farmers, and extension services).

The study identified a big variability in the models used at national level and GHG reporting, where the Yasso07 model is currently the most widely used, and with several countries planning its implementation in the future.

The number of models used at the farm scale to estimate SOC change presented an even bigger variability than those reported at the national scale, including some of the models included in the national scale, but also incorporating smaller spatial models intended for use at the farm scale, at the field scale or even at smaller scales. Most of the models are intended for mineral soils, both arable or grasslands, and only a few are reported for organic soils and/or other land use.

A big heterogeneity was also present in the reported soil quality models (besides those used for accounting for SOC change). Two models included in the national and farm scale are also included here (RothC and Yasso07). The most reported soil quality models focus on greenhouse gas (GHG) emissions estimation and leaching, and are mainly related to the nitrogen cycle, but also to other nutrients, and soil physical properties.

Our results show that synergies derived from European collaborations are not fully used but offer the possibility to enhance the quality of model applications for national GHG reporting and at smaller scales for the support of farm management.

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Table of Contents

List of Tables

List of Figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 862695

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List of acronyms and abbreviations

ER – European region

ENZ – Environmental Zone

SOC – Soil organic carbon

SOM – Soil organic matter

NIR – National Inventory Reports

UNFCC – United Nations Framework Convention on Climate Change

Executive summary

This report provides a synthesis of use of models for accounting and policy support regarding soil organic carbon (SOC) and soil quality, assessed for countries participating in EJP SOIL, as a result of task 2.4.4. Information from twenty-three partners from twenty-one countries was collected through a specially designed questionnaire. The output of these questionnaires was complemented with information gathered from the official national greenhouse gas (GHG) inventory reports.

For the questionnaire we defined models as any kind of algorithm that is able to estimate temporal changes (trends) in soil properties derived from a set of driver data. The questionnaire was divided into three sections: 1) SOC models used in national greenhouse emission inventory; 2) field-farm scale soil organic carbon/matter models used in practice; 3) soil quality models, beside those used for SOC accounting.

We identified that the current use models for SOC accounting in national GHG inventories across European countries is very heterogeneous with many uncertainties reported. Approximately half of the countries are using some kind of model(s) for accounting SOC stock change. Nine models were specifically named but also several unnamed models, but only Yasso07 and ICBM were reported by several countries. A few countries are using multi-model approaches, where models are specific depending on land use category and/or soil type. Models are used in all European regions except Southern Europe.

Heterogeneity in the information presentation by countries about the SOC stock and its change in official national GHG inventory reports is high. This revealed some differences between official reports and current survey responses. According to our survey most countries are planning to improve SOC stock accounting by updating existing approaches or by transition to model based solutions and move to Tier 3 methodology in the GHG inventory.

The number of models used at the farm scale (31 reported in total) to estimate SOC change presented an even bigger variability than those reported at the national scale GHG inventory. Some models (C-Tool, Century/Daycent, DNDC, RothC and Yasso07) were reported in parallel for national scale GHG inventory and farm scale use. Most farm scale models were reported from Central and Western Europe, while Northern and Southern regions reported only a small number of models. The majority of the models are intended for arable or grassland mineral soils, and only a few are for organic soils and/or other land use categories. Most of the models are mainly used by experts and researchers. There is no clear and strong evidence about how widely SOC models/tools are used for practical farming decisions. Mostly it was reported that real use is not known or used by less than 5% of farmers. Thus, more tailor-made solutions based on models are required that reach farmers and support their management decisions.

A big heterogeneity was also present in the reported soil quality models (besides those used for accounting for SOC change). The most reported soil quality models focus on GHG emissions estimation and leaching, and are mainly related to the nitrogen cycle, but also to other nutrients, and soil physical properties.

At national scale within the EU and Europe synergies are not fully explored on the implementation and use of SOC models for GHG reporting. Measures taken to enhance SOC at farm scale must be reportable at national scale. This challenging requirement in SOC accounting call for more collaborative work on SOC modelling in GHG reporting.

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1. Introduction

EJP SOIL - Towards climate-smart sustainable management of agricultural soils, is a European Joint Programme aimed at the enhancement of the contribution of agricultural soils to key societal challenges, such as climate change adaptation and mitigation, sustainable agricultural production, ecosystem services provision, prevention and restoration of land and soil degradation, and biodiversity maintenance. The EJP Soil consortium is composed of 26 European research institutes and universities from 24 different countries.

This report analyses the inputs given by 21 participating countries and 23 research bodies, for task 2.4.4 "Inventory of the use of models for accounting and policy support (soil quality and soil carbon)" which, along with four other stocktake and synthesis, is part of task 2.4 "Synthesis of key soil related issues in the EJP SOIL countries in order to identify gaps and design region relevant research", included in Work Package 2 "A roadmap for Agricultural Soil Management in Europe".

The aim of this synthesis is to collect systematic information from all countries in EJP SOIL on the use of models for accounting for soil carbon and soil quality, and the use also in policy support. The results of this task will give guidance to the development of a roadmap that describes the current state and knowledge gaps in agricultural soil management in Europe and will form the base to develop calls in the 2nd year of EJP SOIL and beyond.

This report is divided into the following sections: introduction, methodology used to collect and analyse the information (section 2), results, presented at: national scale (section 3.1); farm scale (section 3.2), and soil quality models (section 3.3). Finally, the conclusions of the synthesis are presented. Annexes include descriptive table of reported models and access link to combined dataset with partner responses to questionnaire

2. Methodology and data source

2.1. Data Collection

We used a multi-source approach (Figure 1). The primary source of information used for this report was collected through a spreadsheet questionnaire (hereafter the questionnaires) sent to the 24 partners participating in the EJP SOIL. The output of these questionnaires was complemented with information gathered from the official National Inventory Reports (NIR; UNFCCC, 2020) presented by the countries to the UNFCC (United Nations Framework Convention on Climate Change) and from literature. NIR reports were used to get a full overview of how national scale SOC stock change is accounted for. The partners were responsible for the compilation of the information and filling the questionnaire by consulting scientific databases, knowledge repositories, and stakeholders, according to their specific contexts. Twenty-one partners submitted the filled report.

The sources and flows of information for this report are presented in Figure 1.

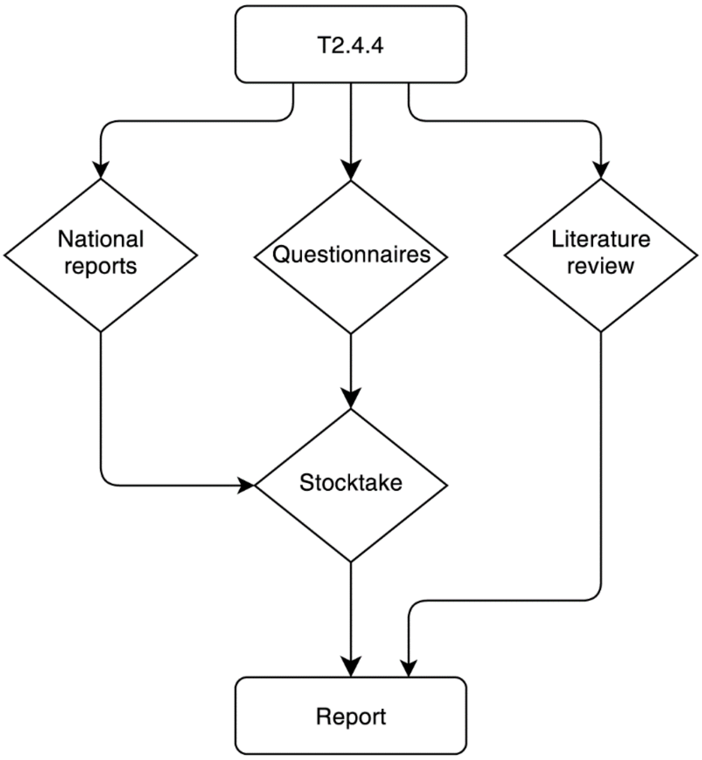

Figure 1. General scheme of data sources and flow for inventory.

For the questionnaire we defined models to be included as any kind of algorithm that is able to estimate temporal changes (trends) in soil properties derived from a set of driver data. Model can be process-based or empirical; can be complex or just some more basic spreadsheet implemented algorithm. Our intention was to include inventory models models/tools that go beyond a fixed soil status (e.g. current soil carbon stocks) but are able to calculate trends in soil properties (e.g. soil carbon stock changes). We focused on models that have a time dimension in order to follow trends in the soil status.

The questionnaire was divided into three sections: 1) national scale; 2) farm-field scale SOC models used in practice; 3) soil quality models, beside those used for SOC accounting (Table 1).

National scale. There is a national obligation to report changes in soil properties at national scale (e.g. changes in soil carbon stocks need to be reported under UNFCCC). Requirements for soil carbon reporting under UNFCCC are increasing. European countries are obliged to shift from Tier 1 methods to country-specific Tier 2 and Tier 3 methods. This often involves models that are used to estimate soil organic carbon trends. We wanted to compile models that are in use or that are planned to be used to estimate trends in national soil carbon stocks.

Farm and field scale models and tools. We aimed to get an overview of field or farm level SOC/SOM models or tools used in practice. There is a high number models developed and used in research but we are facing a knowledge gap of their real use in practice. We asked to include models that are used by farmers, extension services etc. Similar to national scale inventory we excluded models that are only restricted to calculate or predict the current status of SOC/SOM.

Soil quality models. Soil quality, commonly defined as its ability to perform its ecological functions and resist external threats, cannot be successfully estimated by a single indicator. Depending on land use and soil quality assessment purpose various indicators could be used. Beside soil carbon also other soil properties with reasonable time dynamics such as pH, salinity, total nitrogen, mineral nitrogen, soil water, soil fauna etc. have key roles in soil functioning. Here we wanted to compile all models that are used at the field, regional to national scale to prognosis changes in other soil properties or processes other than soil carbon. We excluded models where the focus is on other spheres like hydrosphere or atmosphere (e.g. models that are related to risk assessments of surface- and groundwater pollution).

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Table 1. Structure of the questionnaires used in the data collection.

1. National scale	2. Farm scale	3. Soil quality models
1.1 Current situation	2.1 Current situation	3.1 Current situation
1.1.1 current national reporting of SOC changes 1.1.2 largest source of uncertainty for model results 1.1.3 model spatial resolution 1.1.4 Who is responsible for the national reporting? (e.g. State office, university etc) 1.1.5 Contact of national report of LULUCF (if name is available/known) 1.1.6 How are organic soils accounted for? Same model? 1.1.7 Tier 1, 2 or 3? 1.1.8 National scale SOC model besides GHG reporting	2.1.1 Current tools/models to estimate SOCS/SOM change 2.1.2 Model type (dynamic, static) 2.1.3 Spatial resolution (region, farm, field) 2.1.4 Software, user interface (standalone software, spreadsheet software extension like Excel etc, web-integrated) 2.1.5 Limited to specific land use and/or soil type (no, arable, grassland, mineral soils … etc) 2.1.6 Minimum input data 2.1.7 Output results 2.1.8 Largest source of uncertainty for model results 2.1.9 Web links, references 2.1.10 Use by farmers, extension service (not known, survey results, expert opinion) 2.1.11 Additional remarks	3.1.1 Soil property 3.1.2 currently used model for trends in other soil properties 3.1.3 model spatial resolution 3.1.4 web links, references
1.2 Future plans	2.2 Future plans	3.2 Future plans
1.2.1 planned national reporting of SOC changes	2.2.1 Planned progress on farm/field scale tools and models	3.2.1 models in progress for estimating soil property trends

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2.2. Geographical analysis

The data was characterized geographically using four general European Regions (ER), and 13 Environmental Zones (ENZ) proposed by Metzger et al. (2005).

The following European Regions (ER) were used:

- Northern Europe (Denmark, Norway, Sweden, and Finland)
- Central Europe (Austria, Czech Republic, Estonia, Germany, Hungary, Slovakia, Slovenia, Poland, Lithuania, Latvia, and Switzerland)
- Western Europe (Belgium, France, Netherlands, Ireland, and United Kingdom)
- Southern Europe (Portugal, Spain, Italy, and Turkey)

The Environmental Zones (ENZ) used for this report resulting from the environmental stratification proposed by Metzger et al. (2005) are shown in Figure 2. The following ENZ are represented in this report: Alpine North (ALN); Boral (BOR); Nemoral (NEM); Atlantic North (ATN); Alpine South (ALS); Continental (CON); Atlantic Central (ATC); Pannonian (PAN); Lusitanian (LUS); Anatolian (ANA); Mediterranean Mountains (MDM); Mediterranean North (MDN); Mediterranean South (MDS).

ALN - Alpine North
ALS - Alpine South
ANA - Anatolian
ATC - Atlantic Central
ATN - Atlantic North
BOR - Boral
CON - Continental
LUS - Lusitanian
MDM - Mediterranean Mountains
MDN - Mediterranean North
MDS - Mediterranean South
NEM - Nemoral
PAN - Pannonian

Figure 2. Environmental zones (ENZ) of Europe according to Metzger et al. (2005)

It is important to consider in the analysis of the data presented in this report (and this applies for the three sections of the report: at the national and farm scales, and soil quality models) the different number of countries include in the European Regions (ER) and in the Environmental Zones (ENZ).

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2.3. Data harmonization

The data collected from the partners presented a big variability, hindering further analysis and interpretation. Thus, data harmonization was necessary prior to analysis. In a first step, answers were encoded into categorical variables, with the following criteria:

- Minimize the loss of information.

  The first purpose of harmonization was to preserve as much information as possible from the answers given by the partners.

- Maximize analysability.

  The number of categorical variables was also selected to allow an optimal analysis and interpretation of the collected data.

- Facilitate the detection of clusters and patterns.

  The last goal was the detection of patterns in the collected data.

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3. Results

3.1. National scale - models used for SOC stock change in GHG inventory

3.1.1. Models reported in questionnaires

We aimed to get an overview of models that are in use or that are planned to be used to estimate trends in national soil carbon stocks for greenhouse gas emission inventory. Based on the questionnaire responses, approximately half of countries are using some kind of model(s) for accounting SOC stock change (Figure 3), which go beyond the requirements of Tier 2 accounting. A few countries (BE, FR, LV, SE) are using multiple model approaches. In this case different models are used depending on land use category and/or soil type (mineral, organic).

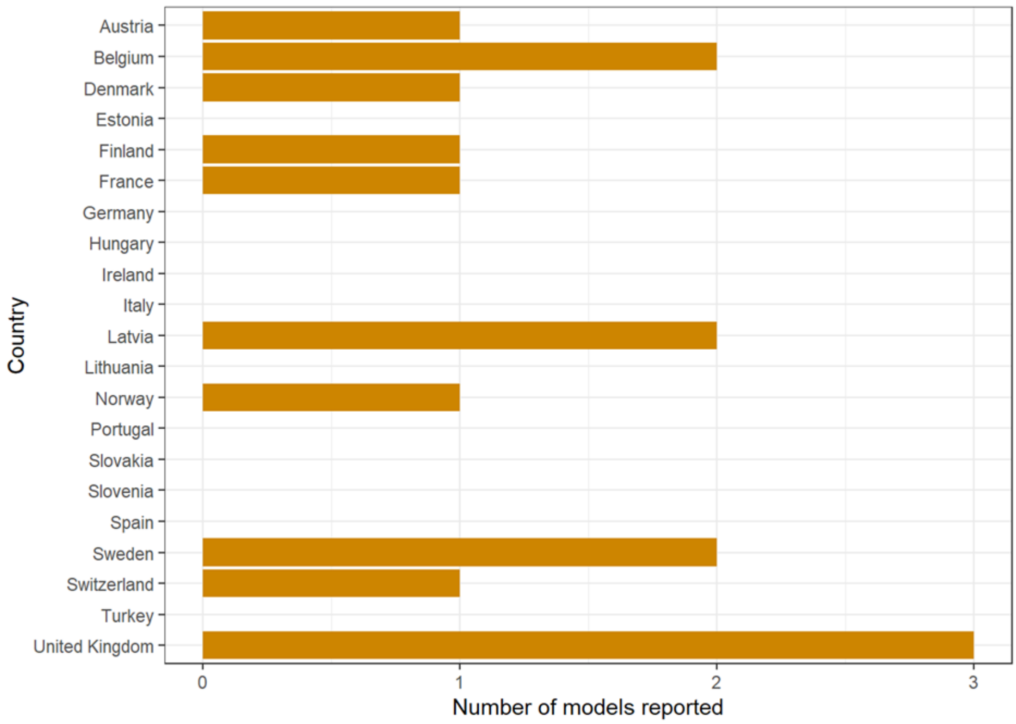

Figure 3. Number of reported models to account for the SOC stock change in national greenhouse emission inventory. Based on questionnaire responses by EJP SOIL partners.

The number of models reported for the different regions (ER, Figure 4) varies from 0 to 6 (for Southern Europe and Western Europe, respectively), while several models are reported for the different environmental zones (ENZ; Figure 5). Only in three regions (Anatolian, Eastern Mountains and Panonian) no model was reported. Each of these zones is only represented each by one country/partner (Turkey for the first two ENZ, and Hungary for the second).

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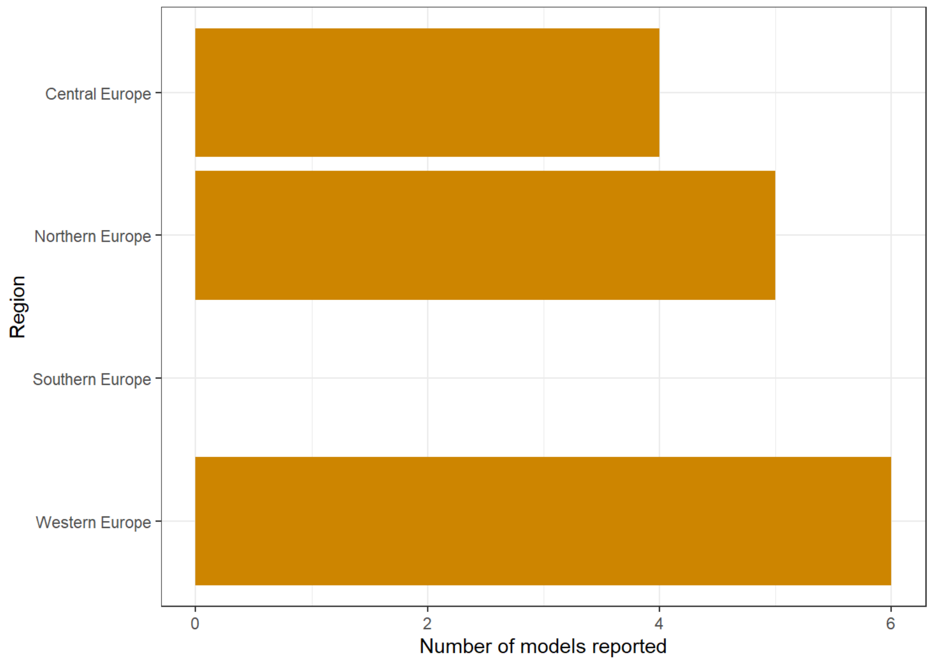

Figure 4. Number of reported models to account SOC stock change in national greenhouse emission inventory by European regions (ER). Based on questionnaire responses by EJP SOIL partners.

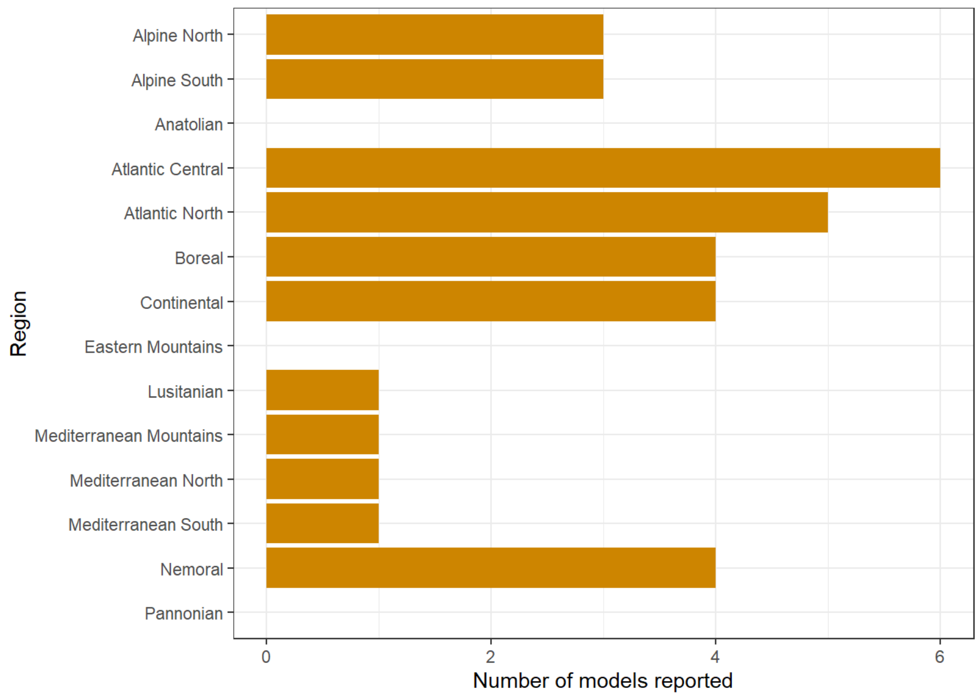

Figure 5. Number of models used to account for SOC stock change in national greenhouse emission inventory by Environmental Zones (ENZ, Metzger, 2005). Based on questionnaire responses by EJP SOIL partners.

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Nine models were specifically named in the questionnaire responses (Figure 6). Only Yasso07 (in AT, FI, LV) and ICBM (in NO, SE) models are used in several countries. All other models are reported only by one country. In addition, several partners reported other models that were not identified by known names. Some of the reported models are specific for some soil type or land use.

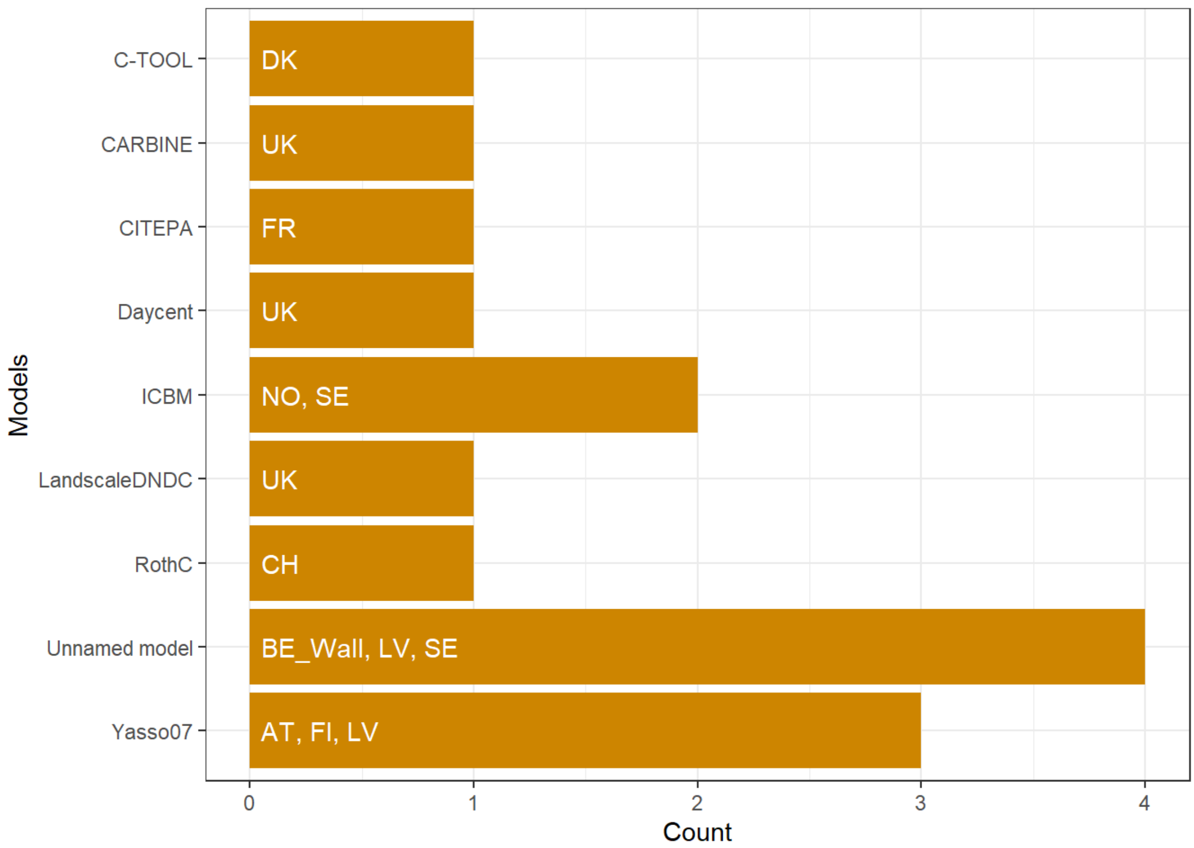

Figure 6. Models used to account SOC stock change in national greenhouse emission inventory. Based on questionnaire responses by EJP SOIL partners.

Several sources of uncertainty for model results were reported. Many similar uncertainty sources were highlighted by several partners: initial SOC stock was the most commonly reported (Austria, Flanders - BE, Germany etc), with SOC stock based on too old survey data (Austria, Flanders - BE). Other sources of uncertainty reported were: spatial resolution; not incorporating management effect or land use change; carbon input data (Latvia, Sweden, Finland).

There is high variability in spatial resolution of the reported models (Figure 7). National, regional and plot scales are present. Regional scale models are quite often used. In several cases spatial resolution is not reported or it was difficult to categorize (indicated as “Other” in the figure).

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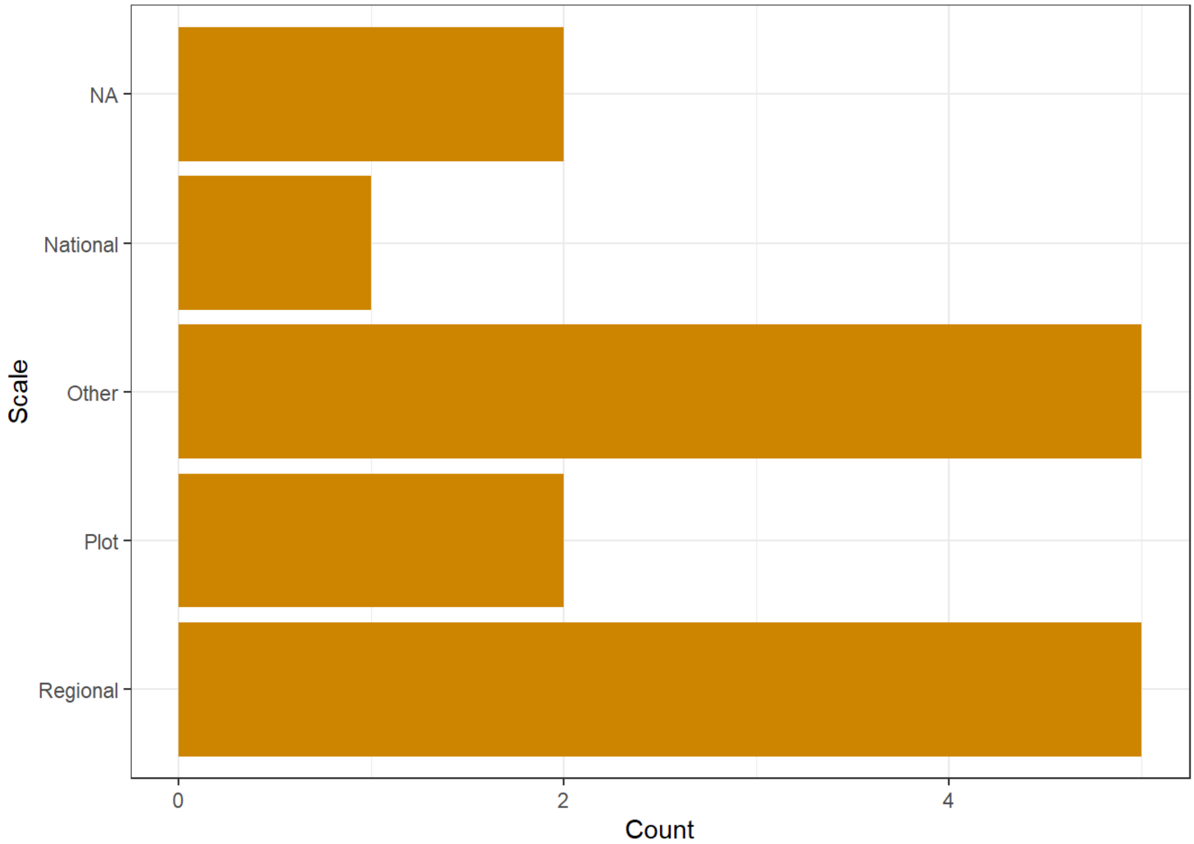

Figure 7. Number of models reported by spatial resolution. Based on questionnaire responses by EJP SOIL partners.

Eight countries reported a different method being used for the national reporting for organic and mineral soils. Three partners responded that organic soils are not taken in account for national inventory (Wallonia BE, Portugal, Slovakia). No specific information was given by the rest of partners.

Latvia reported that the Susi Peatland Simulator is currently under development. This model is also used in Finland besides SOC reporting.

The use of some of the models is limited by land use. For instance, Austria reports that Yasso07 is used for LULUCF, because the model is strong on 'forest remaining forest', but that is struggling in other types of land use and in land use change cases, and therefore a Tier 2 approach is used.

SOC stock change accounting in national GHG inventory varies by countries from Tier 1 to Tier 3 levels. Most countries reported the use of several Tiers (Table 2), with different Tier levels being used depending on land use categories or soil type. In some countries higher Tier levels (2 or 3) are used for SOC stock but for emission factors at Tier 1 level is used (i.e. ET, SE).

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Table 2. Reported Tier for SOC accounting in national GHG inventory. Based on questionnaire responses by EJP SOIL partners.

Country	AT	BE Flan	BE Wall	CH	DE	DK	ES	ET	FI	FR	HU
Tier	2	2		2, 3	2	3	2	1,2	2, 3		

Country	IE	IT	LT	LV	NO	PT	SE	SK	SL	TR	UK
Tier	1, 2	2	2	2, 3	2, 3	1, 2	1, 3	1, 2	1, 2		3

3.1.2. Models reported in official National Inventory Reports

The models used for GHG reporting were also obtained from official and publicly available National Inventory Reports (Figure 8). When the data is compiled and compared with the data collected from the questionnaires (Figure 6), a difference is detected in the number of models by country, with a bigger number of models obtained from the National Inventory Reports (NIR). There are several possible reasons to explain this difference: the model used by the country has not been reported by the partner in the questionnaire (might include cases where model is used for other land categories beside agricultural land); or the model was not properly identified from the NIR in the preparation of this report. It is important to point out that the collection of model use, or lack of model use, was difficult to capture from NIR. Heterogeneity in the information presentation by the different countries about the SOC stock part in inventory reports is very high. From NIR reports we identified that six countries are using the Yasso model, while in current questionnaire responses (section 3.1.1) only three countries reported use of Yasso. As the EJP consortium is focusing on agricultural soils then it might be case that some partners were providing answers only for agricultural land.

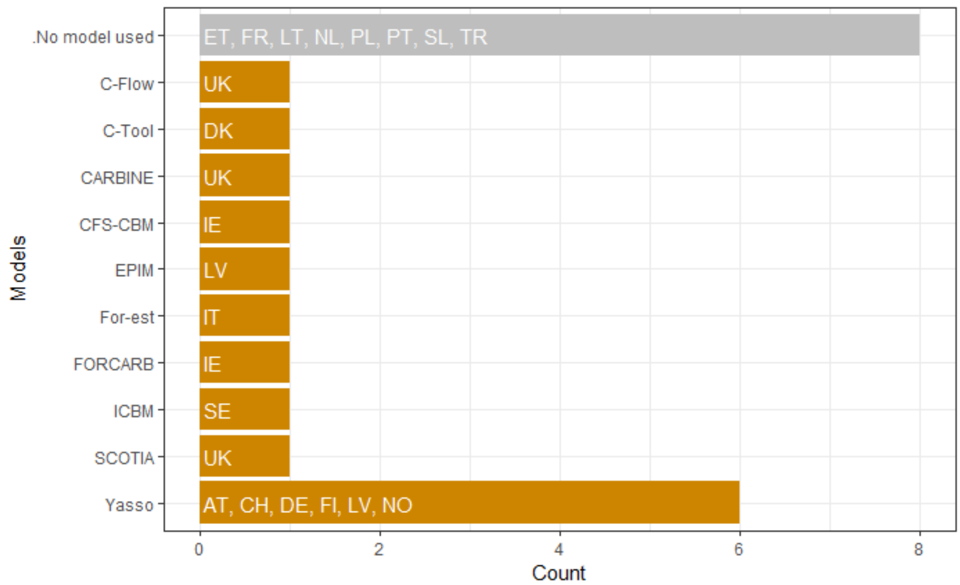

Figure 8. Models used to account SOC stock change in greenhouse gas (GHG) reporting. Based on information from National Inventory Reports (NIR).

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3.1.3. Future plans

We identified that the current use of models for SOC accounting at national GHG inventories in European countries is very heterogeneous and several related uncertainties were reported. The main added value of the information gathered from the questionnaires is that it was possible to identify future plans which could not be detected from national inventory reports. Most countries are planning to improve SOC stock accounting by updating existing approaches or by transition to model based solutions. Several countries are planning to adopt multi-model approaches.

Future plans in SOC models for national scale GHG inventory gathered from the questionnaires can be summarised in four main strategies:

- Transition to model based SOC change accounting and Tier 3 methodology (Flanders - BE, Estonia, Germany, Latvia, Portugal, Slovakia).
- Improve input data (Austria, Latvia, Spain, Sweden), regardless if a model or a Tier 2 approach is used.
- Improve spatial resolution (Finland, France, Hungary) of currently used approach.
- General improvements and/or refinements (Norway, United Kingdom).

Considering the high heterogeneity in current SOC stock accounting across Europe and that most countries are planning to improve the methodology used, joint Pan-European research activities are highly needed to achieve more harmonized SOC accounting at national levels.

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3.2. Farm scale models and tools

The models used for SOC change accounting at the farm or field scale are even more heterogeneous than the models used at the national scale inventory. The most interesting aspect is the variability in the number of models reported by the partners (Figure 9), ranging from as much as nine models reported by Austria to no model reported by several of the partners (Finland, Lithuania, Slovenia, Spain and Turkey).

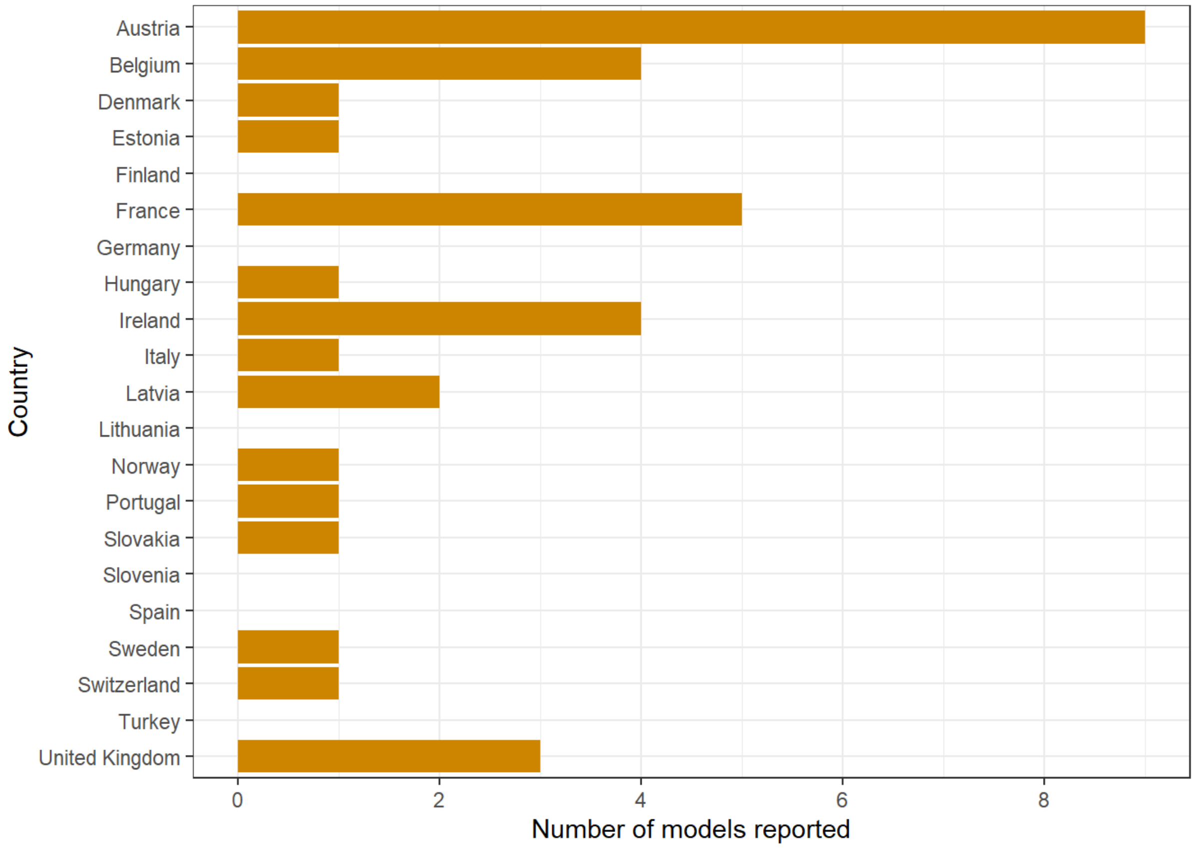

Figure 9. Number of models reported to account for SOC stock change at farm scale. Based on questionnaire responses by EJP SOIL partners.

By region, Central and Western Europe reported respectively 17 and 16 models, while Northern and Southern regions reported only 3 and 2, respectively (Figure 10). But once each country has been connected to the several environmental zones (ENZ) in its territory, all the ENZ represented by the countries in this study except two (Anatolian, Eastern Mountains) are presented (Figure 11).

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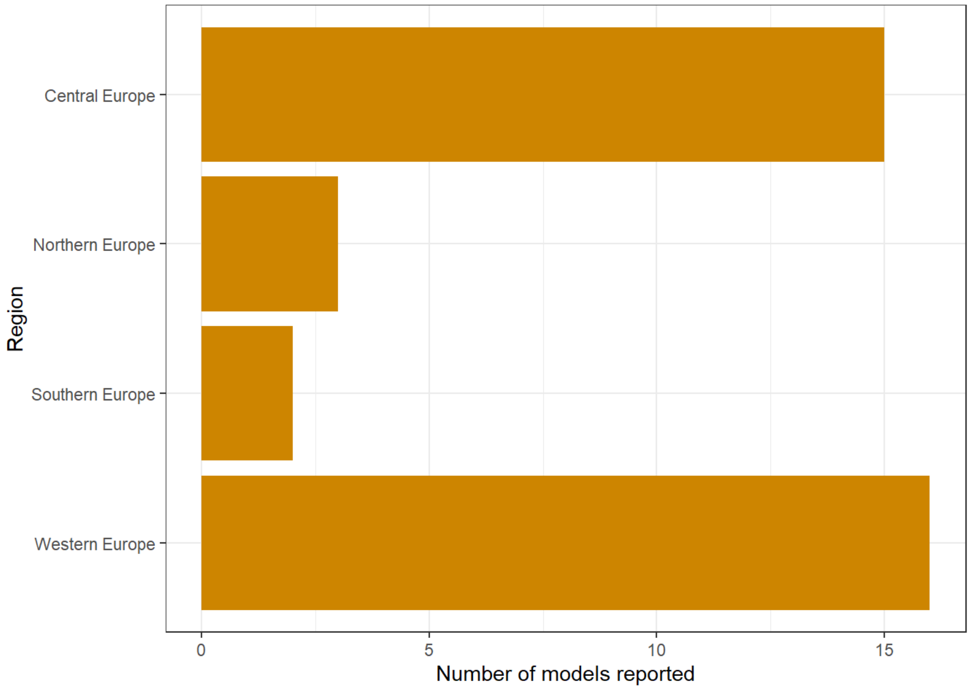

Figure 10. Number of models used to account SOC stock change at farm scale by European regions. Based on questionnaire responses by EJP SOIL partners.

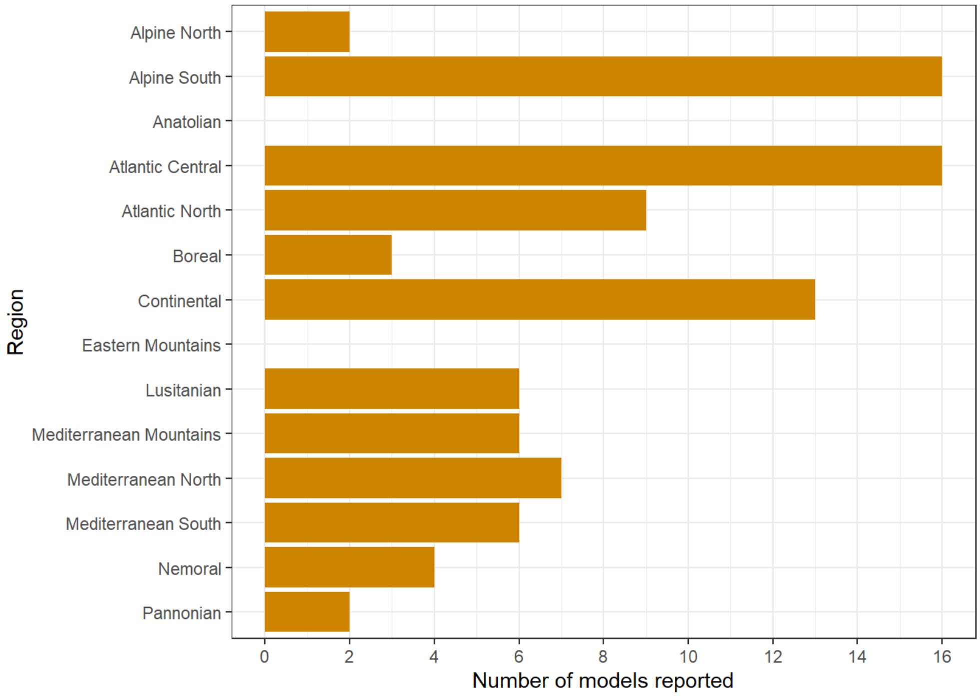

Figure 11. Number of models used to account for SOC stock change in national greenhouse emission inventory by Environmental Zones (ENZ; Metzger, 2005). Based on questionnaire responses by EJP SOIL partners.

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A total of 31 models (Annex I) were reported as used at the farm scale in the participating countries (Figure 12). Of these, several models are also used for SOC change accounting at national scale GHG inventory (C-Tool, Century/Daycent, DNDC, RothC and Yasso07) and others are reported only for farm scale use.

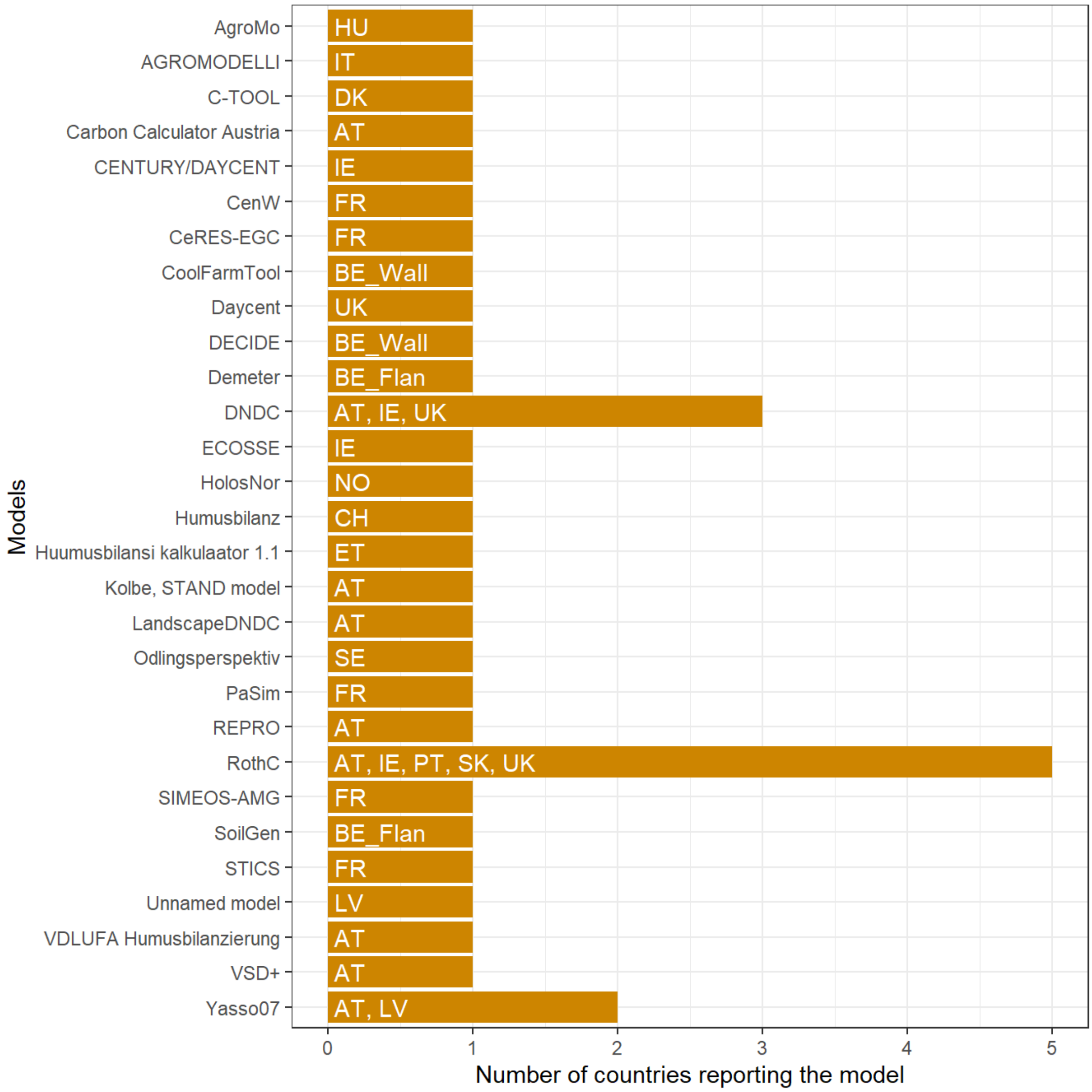

Figure 12. Models used to account SOC stock at farm scale. Based on questionnaire responses by EJP SOIL partners.

Only four models were reported by more than one country: RothC used in five countries (Austria, Ireland, Portugal, Slovakia and United Kingdom), DNDC/LandscapeDNDC used in three countries (Austria, Ireland, United Kingdom); and Yasso07 (Austria and Latvia) and Daycent/Century (United Kingdom and Ireland) in two countries.

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Most of the reported models are of dynamic nature enabling simulation SOC change in time (Figure 13). Some dynamic models (Roth-C, Yasso, STICS) are partly overlapping with models used for national GHG inventory and are also often used by researchers. Five models were reported clearly as static where SOC change for future years could not be simulated in an automated way.

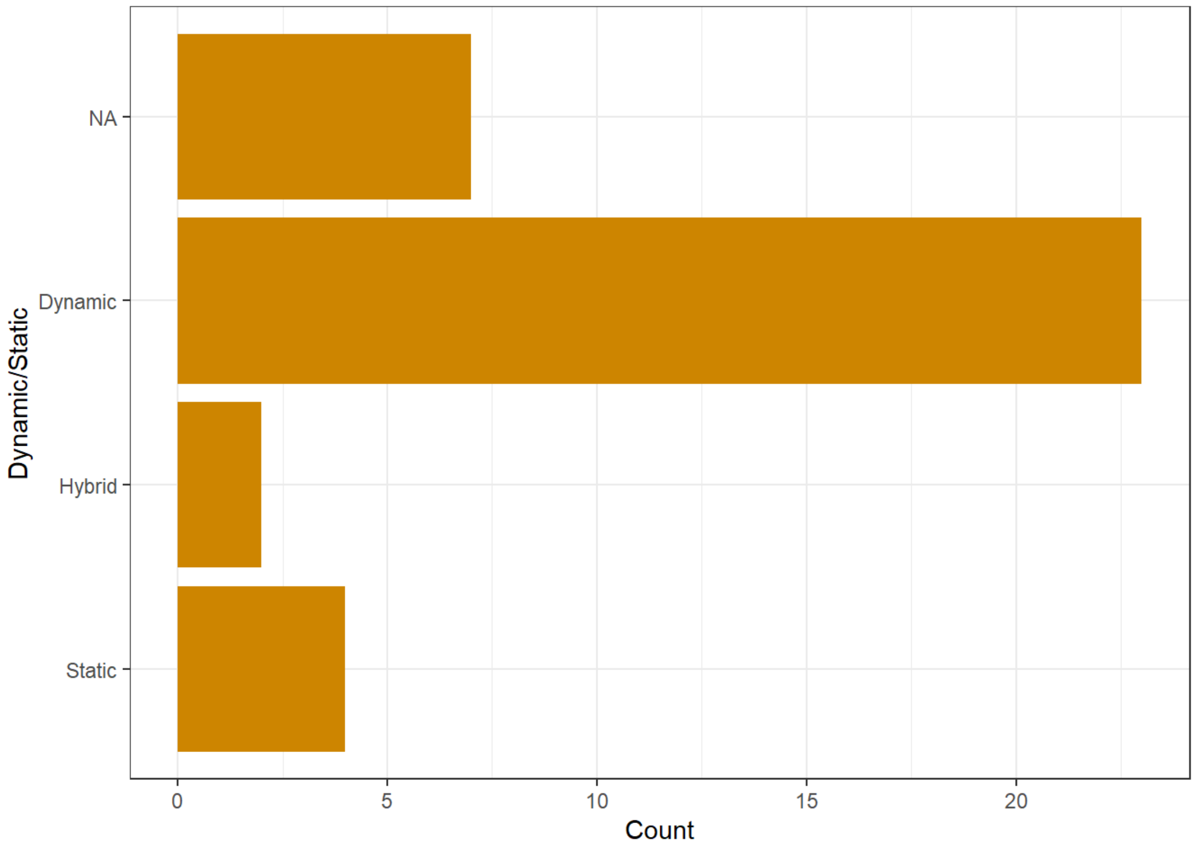

Figure 13. Number of models used to account SOC stock change at farm scale by type of model (Static/Dynamic). Based on questionnaire responses by EJP SOIL partners. NA - not reported.

As expected, almost all the models are intended to be used at the field and farm level (Figure 14), but the majority of the models can also be used at other levels, ranging from the plot/site level to the national (some of the models were also reported at the national scale inventory).

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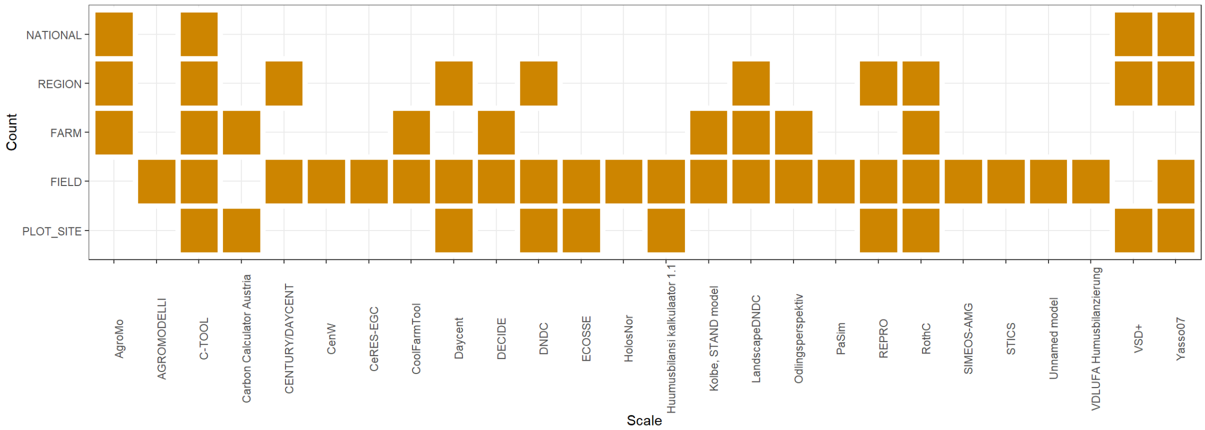

Figure 14. Spatial resolution of the models. Based on questionnaire responses by EJP SOIL partners.

Arable and grassland are the most common land uses considered by the models (Figure 15), while only a few models are intended to be used for other or for multiple land uses, according to the input from partners.

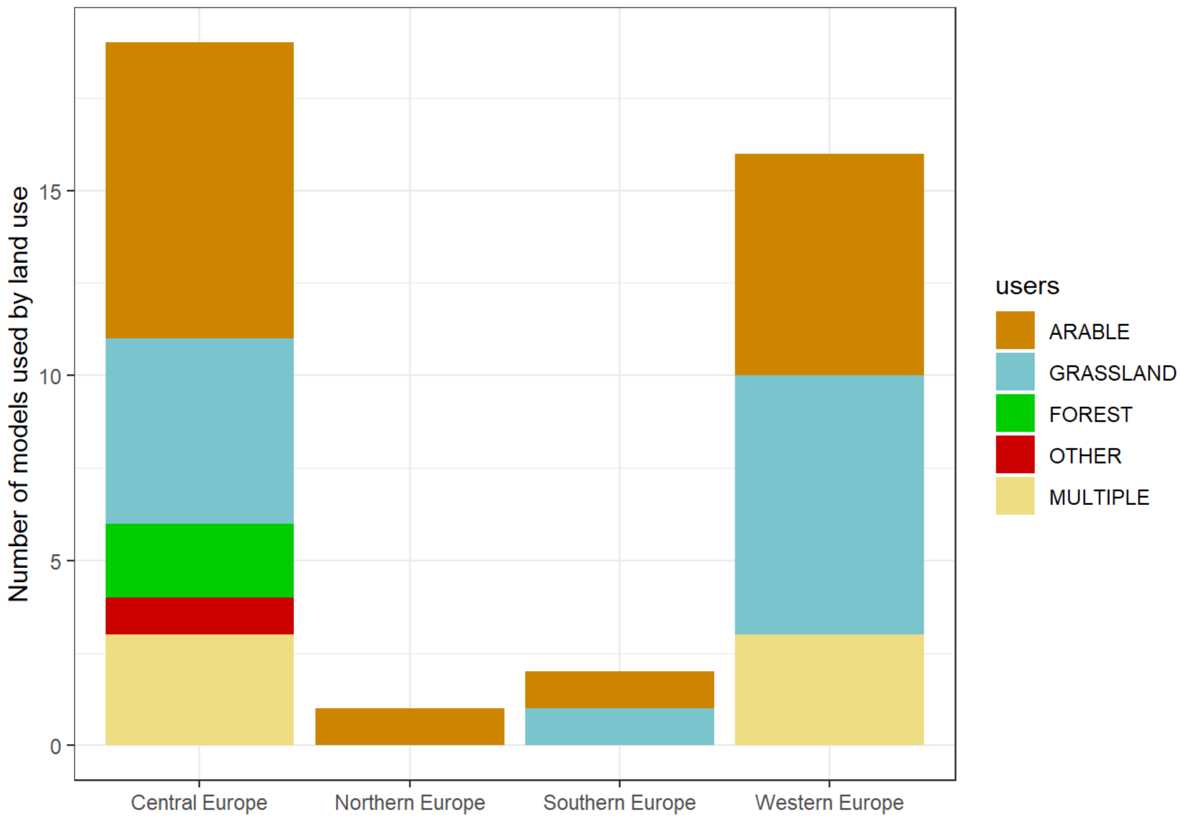

Figure 15. Number of models by land use. Based on questionnaire responses by EJP SOIL partners.

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Regarding the soil type, the majority of the models are exclusively intended to be used for mineral soils, and only a minority are intended for organic soils (Figure 16). It has to be kept in mind that information about the soil type was not reported for more than half of the models.

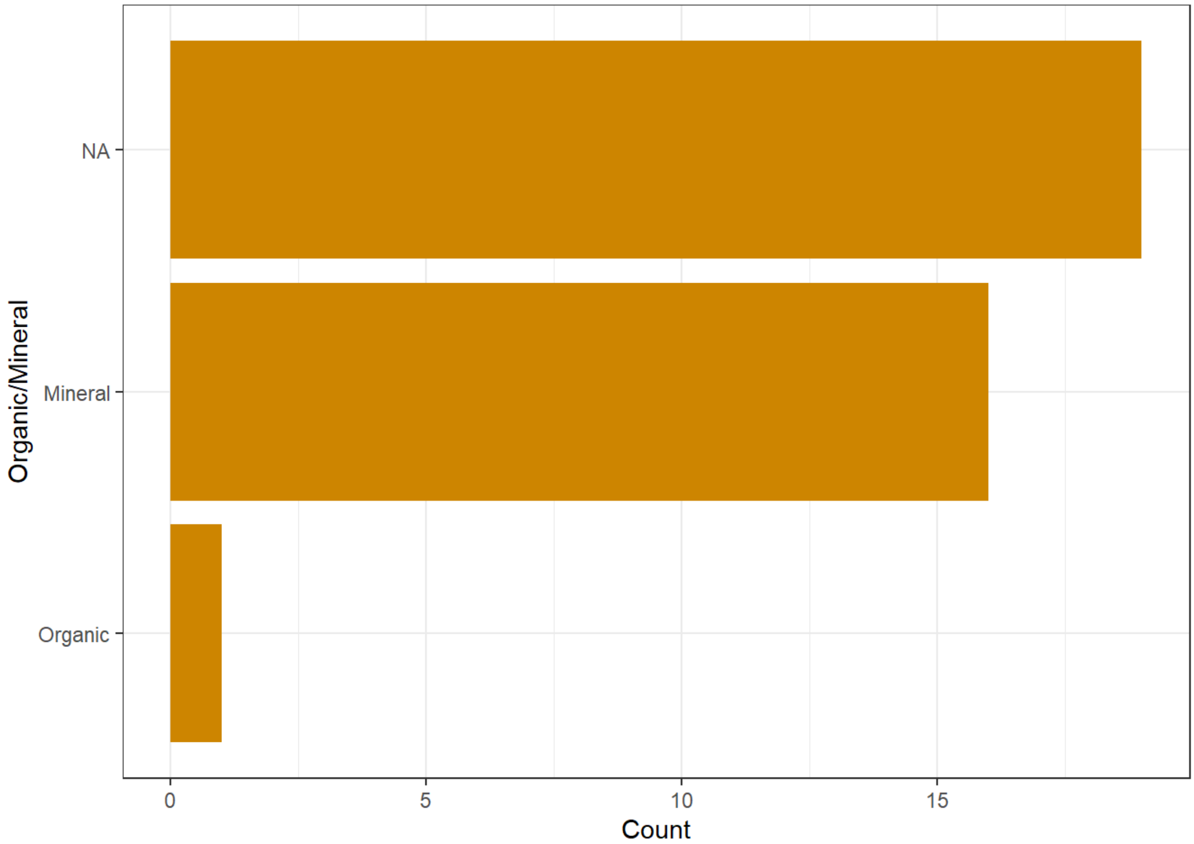

Figure 16. Number of models by soil type (Organic/Mineral). Based on questionnaire responses by EJP partners. NA - not reported.

Input data requirement varies among the different models, with the most common being: soil physical and chemical properties, environmental factors, crop and management, inputs with fertilization and plant residues, yield data. Initial input data is by far the most commonly reported source of uncertainty.

For Western and Central Europe a high proportion of the reported models are used mainly by experts and researchers (Figure 17). The number of models used by research will be much higher than compiled in this stocktake since it was not the intention to comprehensively map them. One aim of the questionnaire was to map models used in farming practice directly by farmers or through extension services. In all regions both these user categories are presented, but it is difficult to generalize from questionnaire responses how widely SOC models/tools are used for practical farming decisions. Even for models originally designed for farm level use no clear evidence was given of their widespread use in practice. It was generally reported that real use is not known or the model is used by less than 5% of farmers. Thus, more work is required to develop tailor-based solutions for farmers that will be taken up easily by farmers.

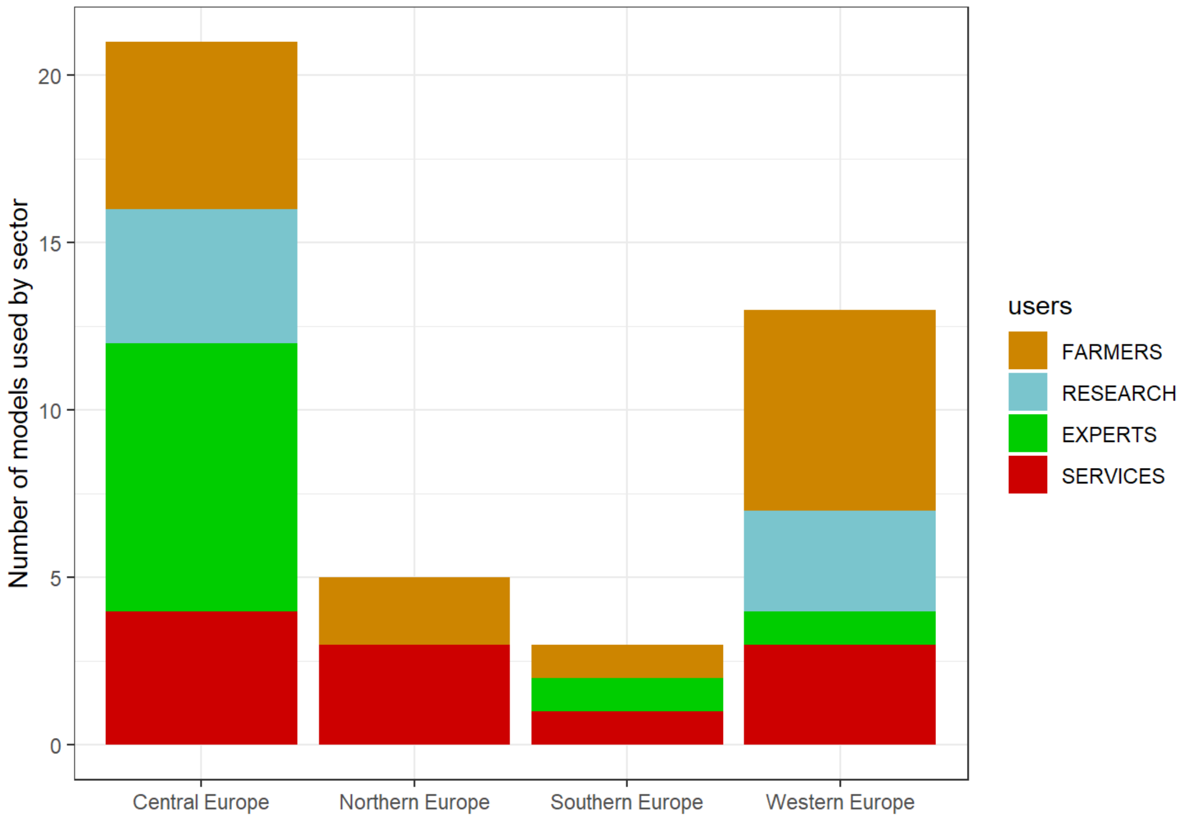

Figure 17. Number of models by user categories and European Regions. Based on questionnaire responses by EJP SOIL partners.

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3.3. Soil quality models

Here we aimed to compile models that are used to capture changes in other soil quality indicators properties, processes or functions beside SOC. The number of soil quality models reported was also very variable among the partners, ranging from nine models for Belgium (combining the answers from Flanders and Wallonia) and no model reported for half of the countries (Figure 18). It is surprising that for most countries none or only one soil quality model was reported. This is most probably due to the unevenness in partner responses and might not reflect the real situation.

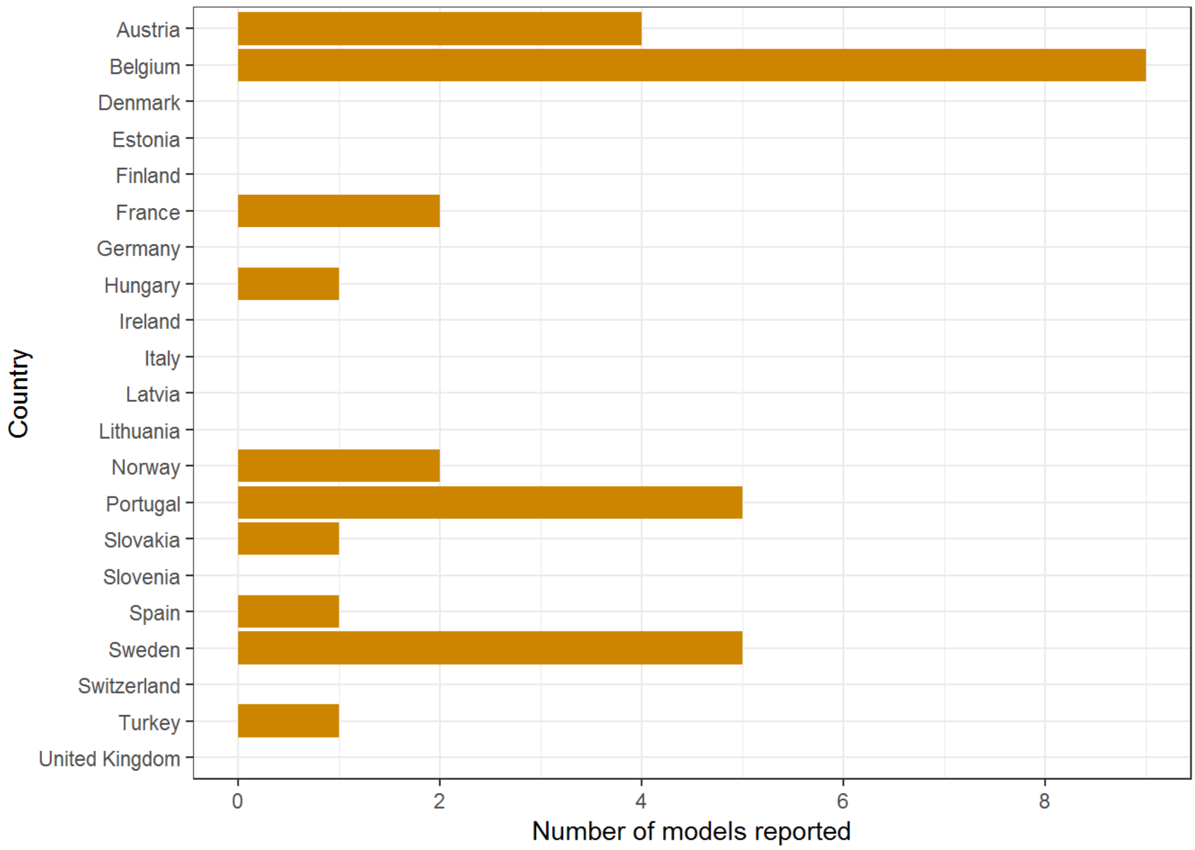

Figure 18. Number of soil quality models (besides those used for SOC reporting). Based on questionnaire responses by EJP SOIL partners.

No clear differences or patterns could be found in the number of models reported by region (ER; Figure 19) or environmental zone (ENZ; Figure 20). The ENZ with less models reported are those represented by only one country (Annatolian, Eastern Mountains and Pannonian) and the Atlantic North (represented by six countries), which seems under-represented.

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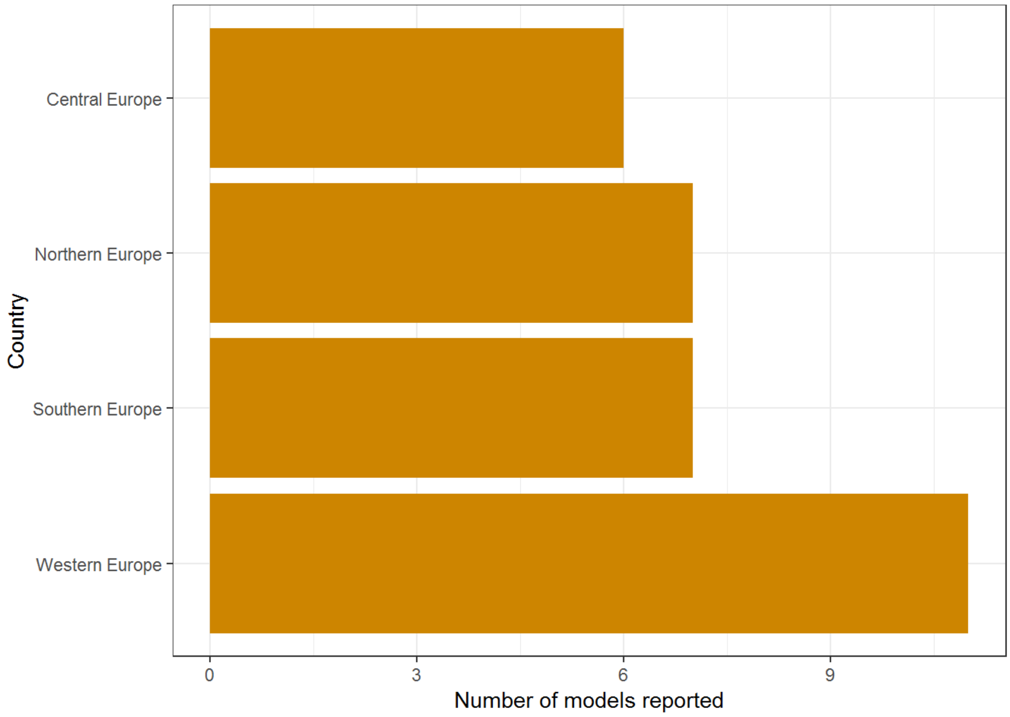

Figure 19. Number of reported soil quality models (besides SOC accounting). Based on questionnaire responses by EJP SOIL partners.

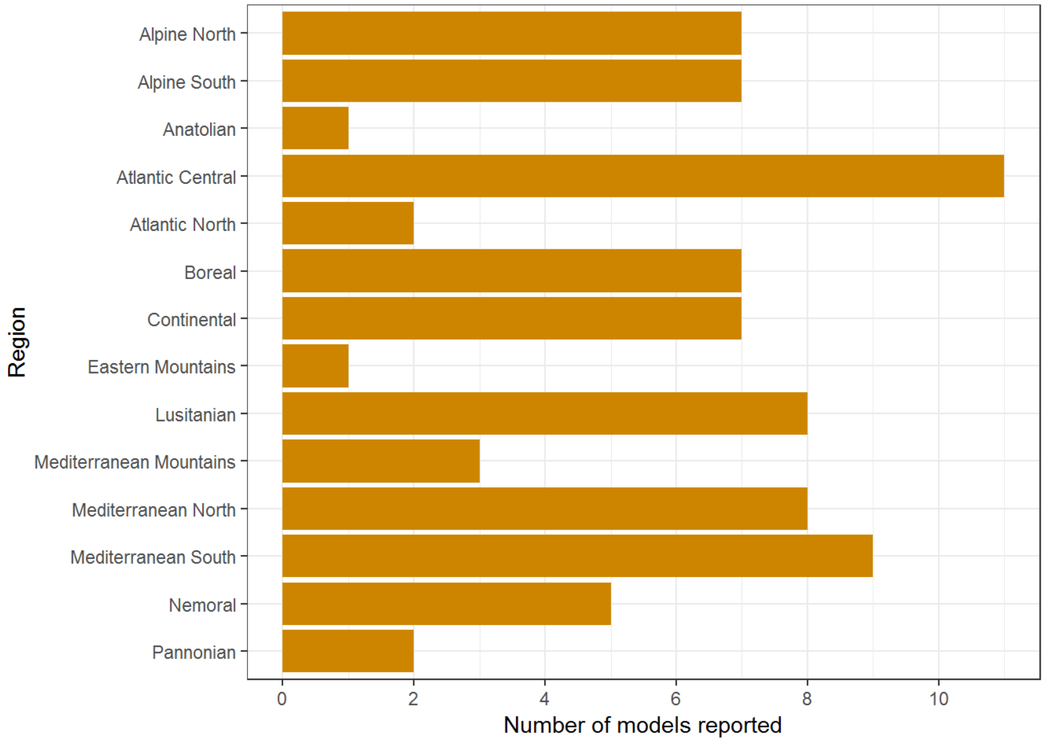

Figure 20. Number of reported soil quality models by environmental zones (ENZ; Metzger, 2005). Based on questionnaire responses by EJP SOIL partners.

Regarding the individual models, no model stands out among the others in terms of countries reporting its use (Figure 21); only two models are reported by more than one country (PESERA and Terramino). Four reported models were unnamed. Two of the models (LandscapeDNDC and Yasso07) were also reported at national and farm scale questionnaires.

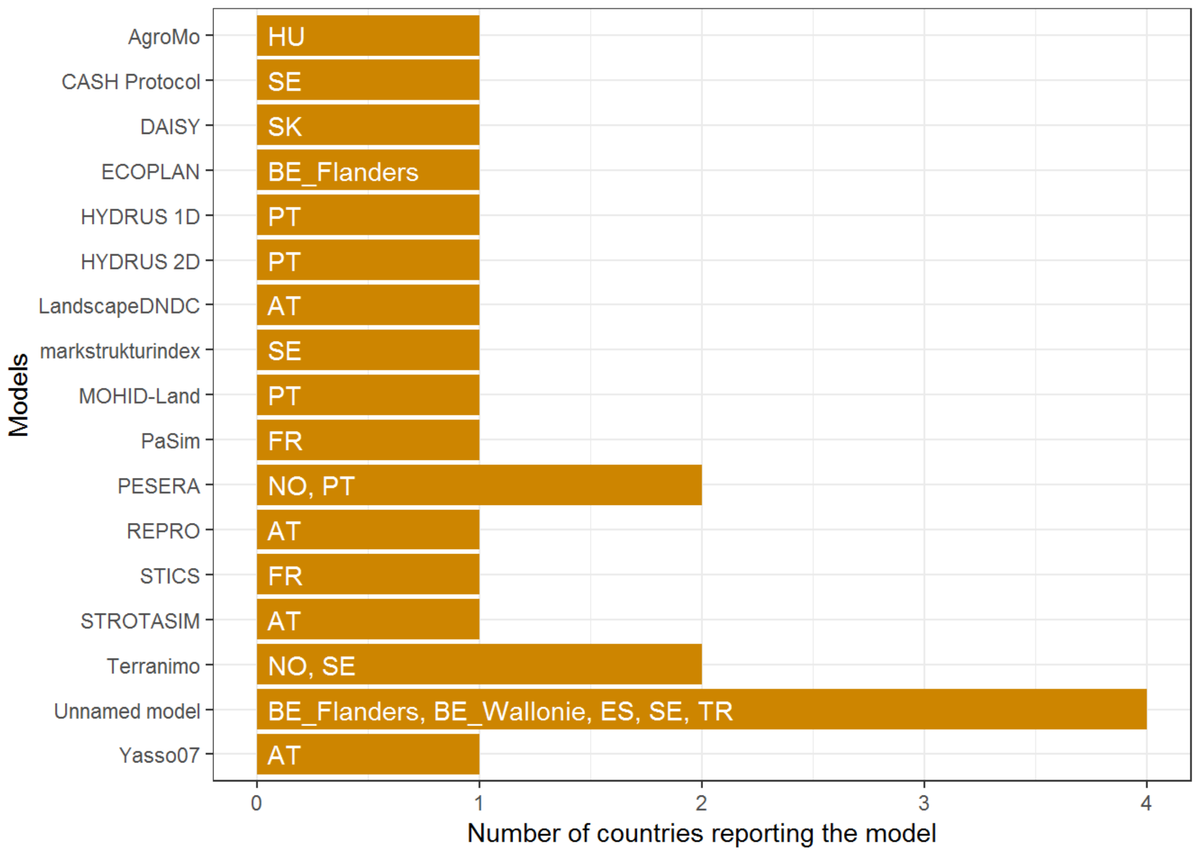

Figure 21. Models reported for soil quality (besides SOC change). Based on questionnaire responses by EJP SOIL partners.

The properties considered by the soil quality models (besides SOC) could be generalized in four groups: nitrogen cycle, greenhouse gas (GHG) emissions, leaching and other properties. Other properties are related to soil physical properties, such as soil structure and compaction, soil salinity, or other content of other nutrients. Properties related to the nitrogen cycle were the most commonly reported, followed by leaching and GHG, which were similarly reported (Figure 22).

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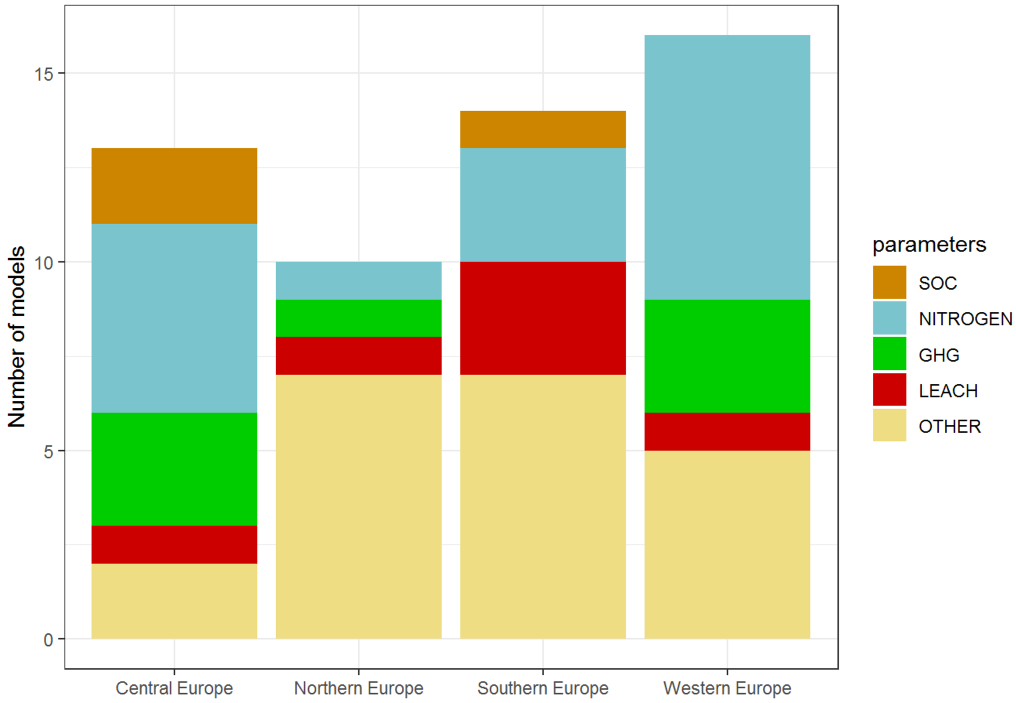

Figure 22. Models reported by soil property. Based on questionnaire responses by EJP SOIL partners.

Field scale was the most commonly reported for soil quality models (Figure 22), but contrary to the models reported for the farm scale section (Figure 14), the models are rarely applied to the other scales.

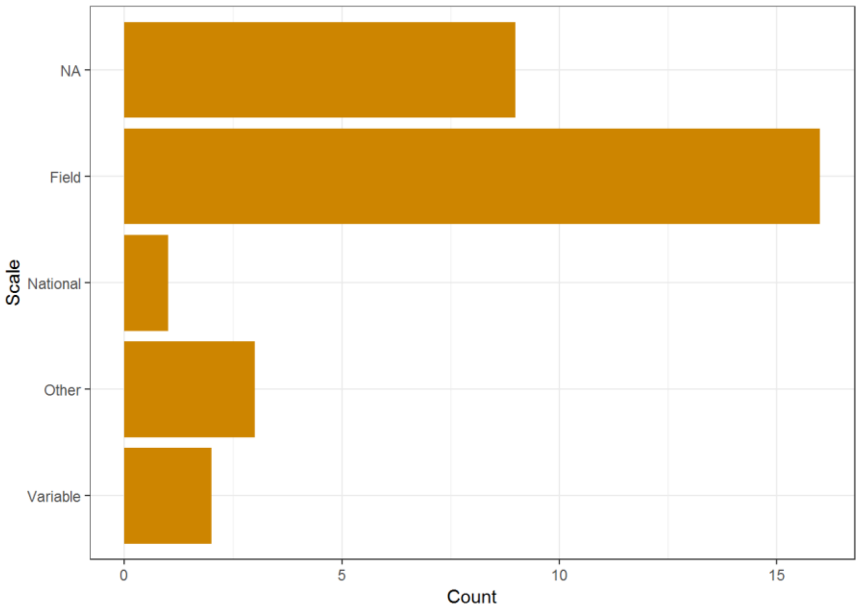

Figure 23. Reported spatial scale of soil quality models. Based on questionnaire responses by EJP SOIL partners.

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4. Limitations of the synthesis

The main challenge in the composition of a synthesis of model use is the high variability in the use of models in the different participating countries. This task was also hindered by the heterogeneity in the information submitted by the different partners. Unevenness in partner responses was especially big for soil quality model questionnaires and this section might not reflect the real situation in the country.

Another aspect that comes out from the results of this synthesis and which would require a deeper analysis is the relation between policy and model development. Policy targets, combined with many other factors (such as resources availability, scientific knowledge etc.), are going to result in the development of updated or newly developed models, and also the purpose and the effective practical implementation of these models. But, also, the output of these models, especially those used at the national scale, can affect future policy making. This is especially true for models predicting or considering the effects of climate change.

This lack of harmonisation can also be found in the National Inventory Reports (NIR) elaborated for the reporting to the UNFCCC, where often information regarding the way SOC changes are handled is not clear. This is frequently related to different methodologies or different Tier level approaches used for the calculation of SOC changes for different soil types or land uses.

Finally, not all models reported at national and farm scales are directly considering SOC change, thus not complying with the model definition set for this stock take.

We identified that the majority of models are used by researchers or experts. Their outputs are most probably used also for impact assessment of policies (agri-environmental, climate change) and for policy driven reporting across Europe. We could not collect reliable data of how widespread is the use of models for practical farm level decision making. This would require a more specific and focused survey.

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5. Conclusions

The main conclusion from the study is the high variability in the use of models independently of studied scale and purpose. This, variability may reflect the variability in pedo-climatic conditions and farming diversity throughout Europe. It may also indicate a lack of collaborative work between European institutions responsible for GHG and SOC reporting and mode development. The variability of methodological approaches and models hinders the comparability of the results across regions and countries. Supranational organizations such as the UNFCCC should guide for the harmonisation in the models used at least at the national scale, and especially when reporting to these organizations. The majority of European countries are planning to improve SOC stock change accounting in national GHG inventory and joint European research programmes could support to achieve more harmonized use of models for that purpose.

The models used at the farm scale are also heterogeneous, as expected. Harmonisation at this level is not a priority objective, and probably not even desirable as it would likely result in distancing these tools from their intended users (if regional or local specificities considered by the model are ignored).

In the models intended for the farm level, there is a high uncertainty, clearly shown in the responses collected from the partners, on the real use of the models among the different stakeholders, and especially among farmers. Identifying the reasons behind the low use of the models is complex, but a special effort should be placed in co-developing models and tools together with the intended users (optimizing the necessary input data, making easier GUIs, etc.) and promoting the use of the models among its intended users. Regarding farm models, another desirable characteristic of the models would be to allow upscaling or aggregation of the discrete farm data to the national scale, although this is beyond the scope of this report.

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References

Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A. and Watkins, J.W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, 14, pp. 549–563.

UNFCCC, 2020. https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/national-inventory-submissions-2020. Accessed: February 1, 2021.

Annex I

An online table with the reported models in farm scale questionnaire is available in Google Drive at the following address:
https://drive.google.com/file/d/1TZeypO7l1xGpNBqpMMuE6SJZkVxa9wE-/view?usp=sharing

Annex II

An online table with the complete information provided by the participating countries is available in Google Drive at the following address:

https://drive.google.com/file/d/1mWN-A1F57SU0Ht740Tc31vkA75VEtqPn/

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