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Estimating future emissions from land use, land use change and forestry

Ecosystem services in forward-looking modelling

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Contents

Abstract

Although complex systems such as land systems cannot be fully represented with models, they stimulate discussion that can help understand the potential risks of trade-offs between ecosystem services when there are pressures on land-based systems. We are building upon a flexible and modular spatially-explicit land use modelling platform to enhance the role of ecosystem services in our modelling approach by allowing the user to prioritise ecosystem services as part of the decision process in the model. Furthermore, the output will report the trade-offs in ecosystem services for different scenarios.

In this report, we describe the implementation of the ecosystem service "climate regulation" in the LUISA-BEES (Land Use Integrated Sustainability Assessment – Bioeconomy and Ecosystem Service) land use modelling platform. Here we have developed a spatially-explicit Land Use, Land Use Change and Forestry (LULUCF) module to estimate the associated emissions in CO_2 equivalent, under different biomass demand scenarios in the EU. The specificities of this module, and the rationale behind its development, are described.

The results of the model run between 2012-2020 are compared with the UNFCCC reporting for 2020 in the CRF tables (2022 submissions). Results show important discrepancies between the reporting and the modelling output. These are discussed and suggestions for improvements are presented.

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1 Introduction

The EU bioeconomy is a means to achieve a green transition. For this reason, when referring to “bioeconomy policies” we refer to all the policies that aim at enabling a green transition. These are multiple and collectively very far reaching, beyond the EU Bioeconomy Strategy itself. It is this broad nature that forces us to ensure that the real impacts of a green transition, through its different bioeconomy-related mechanisms, are known, or at least acknowledged. With this premise, a simplified version of the land use modelling platform LUISA[1] (Perez-Soba et al. 2010) is undergoing a series of changes to equip it with some tools to be able to better assess the coherence between the bioeconomy and related sectoral policy agendas, and the wider Green Deal objectives (European Commission 2019). This model, a fork of the original LUISA model, is hereafter nominated “LUISA-BEES” (Land Use Integrated Sustainability Assessment – Bioeconomy and Ecosystem Services).

The EU Bioeconomy, as defined in the 2018 Strategy (EC, 2018) is bound to maintaining and restoring the ecosystems upon which the bioeconomy is based. The mapping and assessment of the state of ecosystem services is acknowledged and endorsed in the EU Biodiversity Strategy (EC, 2020). Ecosystem services are defined as the ecosystem contribution to economic activities and human well-being (MA 2005, TEEB 2010, Haines-Young and Potschin 2018). Examples of ecosystem services range from the biomass provision (e.g. crop, timber and fisheries) to the filtration of pollutants (from air, water and soil) to the protection from natural hazards (e.g. flooding and landslides) and maintenance of habitats directly and indirectly used and valued by people (e.g. pollination, pest control and carbon sequestration).

The European Commission has tested and implemented general guidelines compliant with the SEEA EA, by developing an operational approach: the Integrated system for Natural Capital Accounting (INCA). As described by the INCA framework, which are compliant with the UN standards, the generation of ecosystem services depends on the ecosystem potential, which in turn depends on land cover and use and the way it is managed (La Notte et al., 2019a). Here we leverage the link between land use and land use changes, and their implications on ecosystem services.

Complex systems such as land systems, which include the human interaction with land, cannot be fully represented with one model or even with several models, however they may help us to tell useful stories about complex problems (Giampietro & Bukkens, 2022). Forward-looking modelling is a tool that can be useful if described honestly, transparently and without pretentiousness. In the work described here, there is no attempt to forecast the future, or produce a “truth machine”, but rather to stimulate discussion through the development of a heuristic tool that can help to understand the potential risks of trade-offs between ecosystem services when there are pressures on land-based systems. Modelling can be useful in allowing non-linear unexpected results from multiple parameters to surface. Clearly value choices are a part of the model parametrisation and this can be seen as a drawback, but it can also be used as a lever for scenario development if described plainly and transparently.

In order to assess the trade-offs, the ecosystem services have to be well represented in the model. To represent these properly, thematic experts with their knowledge of biophysical processes are involved in this work. This requires as stepwise process. In this report, we focus on the development of a LULUCF module for climate regulation.

The geo-spatial approach to LULUCF reporting is required under Regulation (EU) 2018/841. Furthermore, this spatially explicit approach becomes interesting when assessing ecosystem services that are sensitive to geolocation, such as flood mitigation and pollination. In this way, this approach will be capable of informing policies at any scale (local, regional, national or EU) of nature restoration or protection laws, whose characteristic is to be spatially-explicit.

This report details the main characteristics of the LULUCF module developed in LUISA-BEES to estimate CO_2 equivalent emissions from land use, land use change and forestry (LULUCF) under different scenarios. It contributes to the wider goal of incorporating the concept of ecosystem services into the land use model. With respect to GHG emissions modelling, this exercise could serve to set a point from where move forward with respect to the possibility of using process-based modelling for reporting purposes.

[1] https://joint-research-centre.ec.europa.eu/luisa_en

2 Ecosystem service potential and ecosystem service use

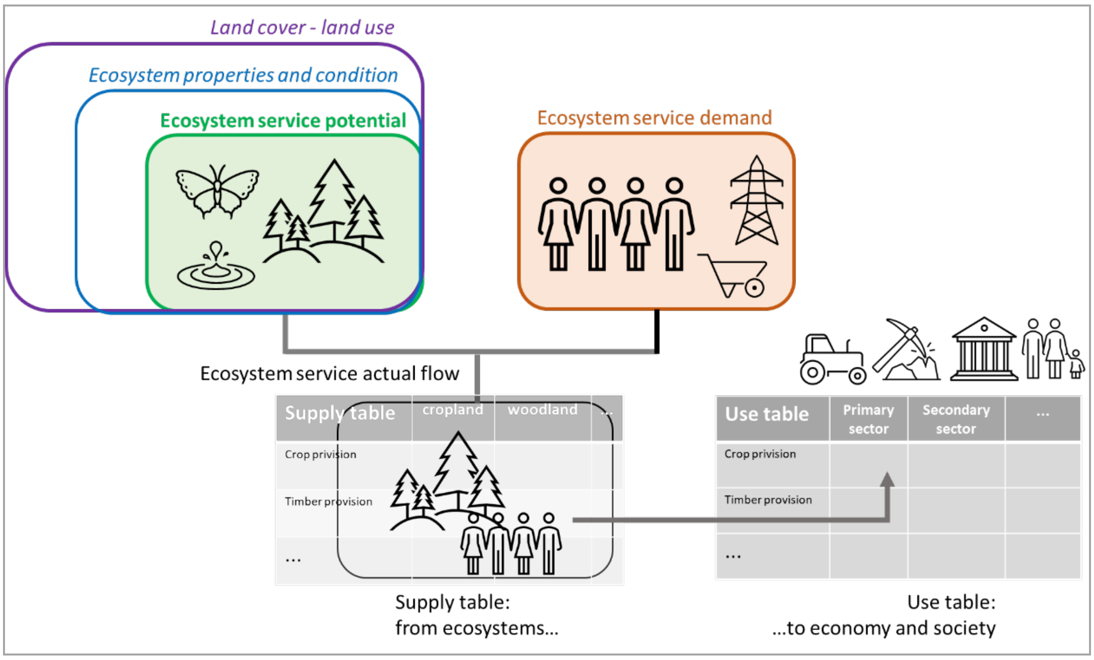
The socio-economic system is highly dependent on healthy ecosystems, whose structure and functions, in combination with other inputs, generate ecosystem services. A constant flow of services is the basis of human well-being, e.g. from the provision of biomass, to the removal of pollutants and protection against hazards.

Ecosystem properties and condition provide the necessary ecological processes for the ecosystem service potentials (Burkhard and Maes, 2017). Specifically, properties (such as soil type and slope gradient) describe the character and structure of an ecosystem, and conditions (such as species composition or pollutants' concentration) describe its integrity and health status. Land use and land cover provide the basis to measure ecosystem properties and conditions that together determine the ability to generate services (i.e. potentials). The ecosystem service potential represents what ecosystems could provide, but not necessarily what is used, which is driven by a demand for a service (La Notte et al. 2019a). The match between the ecosystem service potential and demand generates the ecosystem service actual flow (or use). For example: the presence of woodland and forests (upstream) to mitigate the risk of flooding is a service in a floodplain (downstream) with human settlements and economic assets (Vallecillo et al. 2019). Spatial explicitness is key to determine:

- the properties and conditions of ecosystems according to their land cover –land use;
- whether there is a demand for ecosystem services;
- whether the needed ecosystems are present to provide the demanded services.

Ecosystem properties and condition reflect the type of ecosystem as the result of a specific land use. Ecosystem services are in turn generated by ecological processes within their area of influence such as catchments, habitats, natural regions and land use units. The underpinning linkage is visually simplified by reporting the INCA approach, as depicted in Figure 1.

Figure 1. From land cover-land use to economic accounts according to the INCA approach.



Source: JRC, https://ecosystem-accounts.jrc.ec.europa.eu/

As shown in Figure 1, the ecosystem service actual flow represents a sort of entry point to the economy (from an accounting perspective). This flow is called "supply" when considering where it comes from (i.e. ecosystem types) and "use" when considering where it is allocated (i.e. economic sectors and households). To avoid confusion, we will call ecosystem service potential (and not ecosystem service supply) what ecosystems can provide independently whether it will be demanded or not.

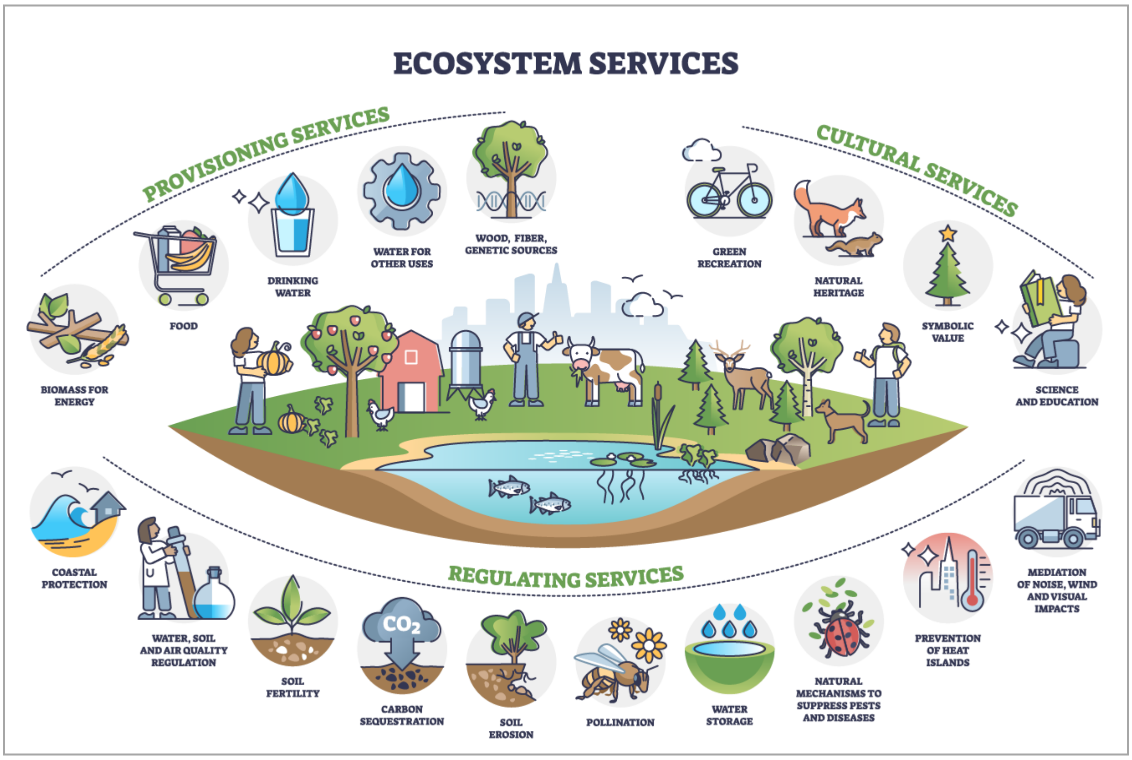
Spatial explicitness is also key to uncover where there is a mismatch between ecosystem service potential and demand. Mismatches can be generated by the absence of ecosystems able to provide the needed services (such as the lack of vegetation to prevent soil erosion) or an unsustainable use of services (such as nitrogen emissions above a sustainability thresholds) (La Notte et al., 2021).

In order to have a more concrete understanding of ecosystem services and their role in land use modelling, the next sections will describe the classification and meaning of a few services assessed, valued and accounted for the INCA project, which are also part of the EU regulation proposal (EC, 2022).

2.1 Ecosystem Services

According to CICES[2], one of the most popular classification system currently used, ecosystem services are generally divided into three broad categories: Provisioning, Regulating and Maintenance, and Cultural (Figure 2).

Figure 2. Schematic depiction of ecosystem services.



Source: Getty Images 1372468124

The centre of the figure above shows the ecosystems that are supplying the services. The icons surrounding the figure represent the services themselves, which can be acquired from one or many ecosystems. In land use modelling terms, these components correspond to the potential and the demand: The potential is the ability of the ecosystem to provide a service while the demand is the expected requirement from society.

In accordance with EU regulation (EC, 2022), the services to monitor are

(a) Provisioning services:

– Crop provision, defined as the ecosystem contributions to the growth of plants, estimated as the amounts of harvested crops that can be attributed to ecological inputs. This is not the total amount of the harvested biomass: the higher the ratio of natural inputs (versus human inputs) the higher the crop provision service. Intensive monocultures (where human inputs are higher than natural inputs) account for a service flow that is

[2] Ref. https://cices.eu/

lower than organic farming or extensive agricultural systems. Crops are meant for various uses including food and fibre production, fodder and energy, and grazed biomass;

– Wood provision, defined as the ecosystem contributions to the growth of trees and other woody biomass, reported as net increment.

(b) Regulating and maintenance services:

– Pollination, defined as the ecosystem contributions by wild pollinators to the production of the above crops, shall be reported in tonnes of pollinator-dependent crops that can be attributed to wild pollinators, by type of crop for the main types of pollinator-dependent crops comprising fruit trees, berries, tomatoes, oilseeds and 'other';

– Air filtration, defined as ecosystem contributions to the filtering of air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly trees, that mitigates the harmful effects of the pollutants, shall be reported in tonnes of fine particulate matter (PM2.5) adsorbed;

– Global climate regulation, defined as the ecosystem contributions to reducing concentrations of greenhouse gases in the atmosphere through the removal (net sequestration) of carbon from the atmosphere and the retention (storage) of carbon in ecosystems. The contributions are reported in terms of tonnes of net sequestration of carbon and tonnes of organic carbon stored in terrestrial ecosystems including above ground and below ground in the first 0.3 meters of the soil (including in peatlands);

– Local climate regulation, defined as the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) in urban areas through the presence of vegetation that improves the living conditions for people and supports economic production, expressed and reported as the reduction of temperature in cities due to the effect of urban vegetation in degrees Celsius on days exceeding 30 degrees Celsius.

(c) Cultural services:

– Nature-based tourism-related services, defined as the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment shall be reported in number of overnight stays in hotels, hostels, camping grounds, etc. that can be attributed to visits to ecosystems.

2.2 Supply of ecosystem services and land use modelling

The bridge between the land use model and the ecosystem services are the *ecosystem types*. Ecosystem types are basically aggregates of the land use classes. The ecosystem types considered in INCA, and compliant with the EU regulation (EC, 2022), are shown in Table 1:

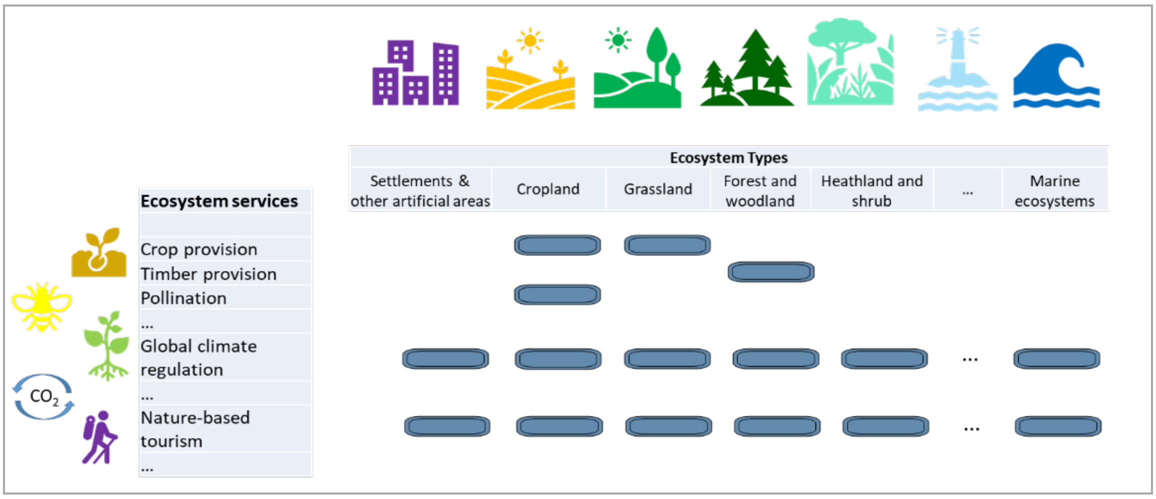
Table 1. Ecosystem types, to be associated to land use classes for modelling purposes.

Category	Name of ecosystem type
1	Settlements and other artificial areas
2	Cropland
3	Grassland (pastures, semi-natural and natural grassland)
4	Forest and woodland
5	Heathland and shrub
6	Sparsely vegetated ecosystems
7	Inland wetlands
8	Rivers and canals
9	Lakes and reservoirs
10	Marine inlets and transitional waters
11	Coastal beaches, dunes and wetlands

12	Marine ecosystems (offshore coastal, shelf and open ocean)

Each ecosystem type can provide one or many ecosystem services, as shown in Figure 3, and fully described and reported La Notte (2019b, 2020, 2021) and in Vallecillo (2018, 2019). Ecosystem services are related to land cover and land use in that these describe the ecosystem types. As the land is converted, the services it provides change.

Figure 3. Relationship between ecosystem types and ecosystem services.



Source: JRC, own elaboration

With this work, we are examining the possibility of integrating the concepts of ecosystem services into the land use modelling platform.

3 Policy context

3.1 Overview

The European Green Deal (EGD) is the EU's strategy to transition to a sustainable development model. The EGD is having considerable impact on where and how biomass is sourced (Mubareka et al, 2022). Increasing the domestic biomass production will have direct and indirect consequences in the way we manage European natural resources. Land use changes, whether they are due for example to the expansion of croplands onto grassland and abandoned lands, or to the increase of forest harvesting rates for the forest-based sectors will affect different EU policy agendas such as biodiversity, food security and sovereignty, energy, climate change, and nature restoration among others. Therefore, understanding how policies both impact and are impacted by land use change, in particular under different levels of biomass demands, could support a coherent approach to the EU bioeconomy-related policies.

A system's level perspective is best adopted when weighing forest-sector climate change mitigation strategies. The EU's forests offset emissions, according to 2016-2018 data, by about -360 Mt CO_2 /year, whilst the overall LULUCF removal is approximately -265 Mt CO_2 /year, which is about 7% of the total EU GHG emissions (Grassi et al, 2021). So the impact of land conversion from and to forests is an important component of the overall GHG budget of the EU.

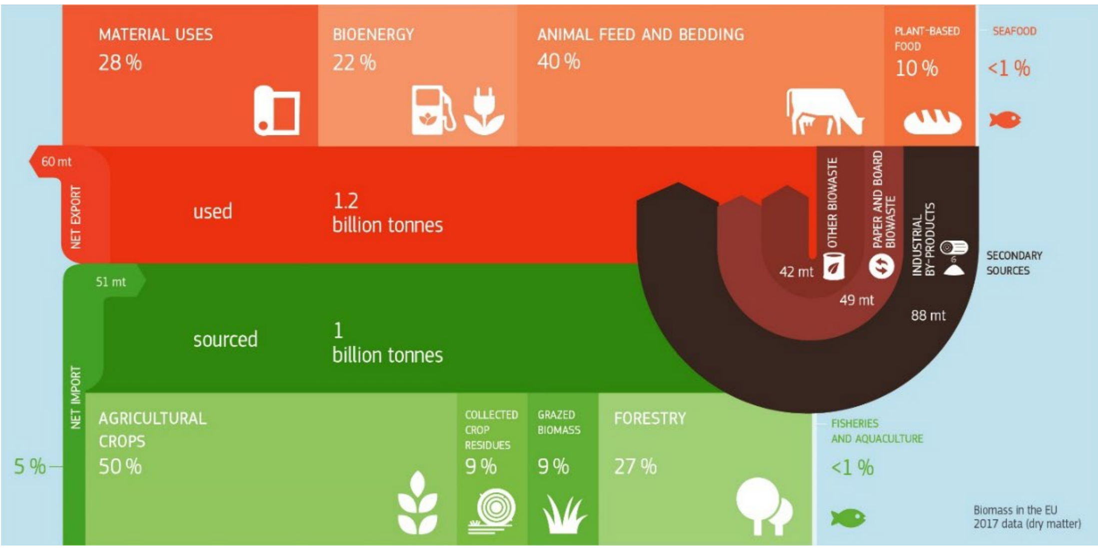
3.2 The EU bioeconomy

The European bioeconomy encompasses a wide range of productive sectors – i.e., agriculture, forestry, fisheries, food, bioenergy and bio-based industry, employing about 17.5 million people in 2019[3] (Ronzon et al, 2020).

Traditional agriculture and its manufactured products represent by far the most important contribution to EU bioeconomy, followed by the forest-based sectors. New services and products (e.g., bio-based chemicals or bioenergy) are still in their early stages.

Figure 4 shows that most of the biomass supply in the EU-27 in 2017 came from agriculture and forestry sectors[4].

Figure 4. EU-27 Biomass supply and use in 2017. *Source: JRC Biomass Mandate[5].*



Source: JRC Biomass Mandate (2022)

[3] https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en?indicatorId=5.2.a.1
[4] https://knowledge4policy.ec.europa.eu/publication/infographics-biomass-sources-uses-eu-27-2017-data_en
[5] https://knowledge4policy.ec.europa.eu/projects-activities/jrc-biomass-mandate_en

The 2018 update of the 2012 Bioeconomy Strategy (EC, 2018a)[6] reinforced the scope of its action towards the 2030 Agenda and SDGs, as well as the Paris Agreement targets, by setting new action plans to: i) Strengthen and scale up bio-based sectors, unlock investments and increase market uptake; ii) Deploy local bioeconomies rapidly across Europe; iii) Understand the ecological boundaries of the bioeconomy. This third action aims at increasing the knowledge base on bioeconomy sustainability dimensions through improved observation, measurement, monitoring and modelling capacities. It recognizes the importance of modelling and quantifying direct and indirect land use changes resulting from increasing demand for different biomass feedstock, to guarantee the optimal use of available natural resources and limit biodiversity, carbon stock and ecosystem services degradation.

3.3 The LULUCF regulation

Regulation (EU) 2018/841[7] (the 'LULUCF regulation') sets the accounting rules for the Land Use, Land-Use Change and Forestry (LULUCF) sector in the EU for 2021–2030, i.e. how the emissions and removals of greenhouse gases from LULUCF will be counted towards the climate targets of the EU[8]. The LULUCF regulation is part of the EU's commitment to reduce overall emissions by at least 40% by 2030 under the Climate and Energy framework[9]. Every Member State must balance its accounted greenhouse gas emissions on the LULUCF sector by an equal amount of accounted greenhouse gas removals ("no debit rule"). Possible surplus removals may be, up to certain limits, used to compensate emissions from the sectors covered by the Effort Sharing Regulation[10] .

The land accounting categories covered by the LULUCF regulation are afforested land, deforested land, managed cropland, managed grassland, managed wetlands, and managed forest land. In this context, 'managed' does not necessarily refer to active management but is used to refer to those land areas reported in the annual national greenhouse gas inventories (GHGIs) for which anthropogenic emissions and removals are reported[11]. For each land accounting category, the emissions and removals from the carbon pools of above-ground biomass, below-ground biomass, litter, dead wood, and soil organic carbon should be included in the accounting. Accounting for managed forest land must include carbon pools above-ground biomass, dead wood and harvested wood products. In this way, the emissions resulting from biomass burning for energy use are included in the LULUCF accounting and, to avoid double-counting, the same emissions are zero-rated in the energy sector accounts.

The accounting rules for different land categories differ from each other: for afforested and deforested land, the total emissions and removals are included in the accounts. For managed forest land, the accounting is done against a projected forest reference level, which represents a benchmark for future emissions and removals that would be expected in the periods 2021-2025 and 2026-2030, if forest management practices continued as they were in 2000-2009 (Korosuo et al., 2021). The forest reference level therefore allows for changes in harvest levels that are due to development of the forest age structure. The aim is to separate the impact of policy changes in forest management – i.e. those which the Member States can still influence – from those decisions that were made already in the past, but whose influence is still seen in the forests.

[6] https://knowledge4policy.ec.europa.eu/publication/updated-bioeconomy-strategy-2018_en

[7] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU. http://data.europa.eu/eli/reg/2018/841/oj

[8] Since land-related fluxes of greenhouse gases are partly affected by natural phenomena and past management, assessing the impact of recent mitigation actions in the LULUCF sector is more difficult than in other sectors (energy, transport). In this context, the accounting rules filter the emissions and removals reported in the national GHGIs with the aim to assess the impact of mitigation actions, and count these towards the climate target.

[9] https://ec.europa.eu/clima/sites/clima/files/strategies/2030/docs/2030_euco_conclusions_en.pdf

[10] Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013. http://data.europa.eu/eli/reg/2018/842/oj

[11] In line with IPCC Guidelines (2006, 2019), GHGIs include emissions and removals from 'managed land', i.e. "where human interventions and practices have been applied to perform production, ecological or social functions".

4 LUISA-BEES integrated modelling framework

The JRC has been developing its modelling capacities in several different applications related to bioeconomy, such as land use change, forestry, agriculture, among others. Although the nature of the data and models is very different from one another, it is possible to bring the salient parts together for practical policy-support. Within the Biomass Mandate[12] , the JRC has put considerable semantic effort towards bringing the concepts of these models together to generate a view of the possible future situation of biomass availability, supply and demand. The strengths of the integrated modelling framework are the spatially-explicit component and the capacity of bringing together and reconciling the requirements from different sectors for land (Mubareka et al., 2018).

In the past, the focus was on the biomass supply side, however with the implementation of the EU Green Deal, the focus is shifting towards a more systemic point of view, and the acknowledgement that the Earth's carrying capacity has limitations. Thus, scenarios of the future have to go beyond producing output from an economic perspective and neglecting the human well-being and loss of life from different scenarios as many Integrated Assessment Modelling Exercises currently tend to do (Stern, 2016), and to begin to model with more realistic assumptions about behaviour and therefore represent a more truthful system (Asefi-Najafabady et al, 2021).

Spatially-explicit modelling allows us to consider localised biophysical and neighbourhood attributes that may affect land use and ecosystem services. For instance, from the LULUCF sector perspective, above and below ground biomass is impacted at a local level, depending on the detailed ecosystem type and condition, which will affect the vulnerability to disturbance in terms of emissions (Cotrufo et al., 2019). Management and conversion type will also impact the emissions at local scale (see, for example, Pilli et al. 2017).

Finally, spatially-explicit modelling is key for the assessment of ecosystem services. For most cultural, regulating and maintenance services there are no raw data which could simply be collected through survey or census, contrary to economic and social statistics. The ecological process underpinning the generation of the service itself needs to be spatially "simulated" to estimate the best proxy for the ecosystem service flow. For instance the nitrogen removal by freshwater ecosystems (used for water purification), the RUSLE equation (used for the soil retention), the curve number (used for flood control), (La Notte et al., 2021, Vallecillo et al, 2019). Ecological process is, in turn, based on ecosystem characteristics, which are in turn dependant on land cover and land use.

The model used to assess land use change in the EU is the "Land Use Integrated Sustainability Assessment – Bioeconomy and Ecosystem Services" configuration (LUISA-BEES). This model's origins, as they were developed for the European Commission in 2010. More details of how the modelling framework functions and its input data and assumptions can be found in Perez-Soba et al., 2010; Lavalle et al., 2011; and Lavalle et al., 2016. The main specifications are shown in Table 2.

Table 2. Main specifications of LUISA-BEES.

Spatial resolution	100m
Geographical coverage	European Union 27
Time step	5 years
Base map	Corine Land Cover map 2018, adjusted to match forest area
Range of simulation	2018-2050

[12] https://knowledge4policy.ec.europa.eu/file/biomass-mandate-jrc_en

The total suitability of land is the result of a combination of factors that express the added value of allocating land to a specific land use purpose and is expressed as a coefficient. Luisa-BEES optimises land-use distributions given a pre-defined demand for space for each land use type, while taking into account that land is finite. Locational utility is included through land-use specific suitability maps, which are the result of a set of physical factors, neighbourhood potential, transition costs, location-specific subsidies or taxes. In addition, the model imposts physical restrictions on transitions. These may be time dependant in the configuration and typically relate to transitional classes such as “young forest”.

The model is written in a declarative language GeoDMS . The GeoDmsRun.exe is an executable written in C++ and can be used to produce calculation results from a Command Prompt or batch files. GeoDMS is available as open source.

4.1 A review of the land use model principles

External sectoral models and data are typically used to translate assumptions on socioeconomic trends and policy under different scenarios into projections for agricultural, forest and built areas to a future land use. Land use models, such as LUISA-BEES, use the exogenous projections as input, allocating these quantities (i.e., number of hectares, number of people) as a function of biophysical attributes, land use constraints, among others, outputting future land use maps and associated transition matrices.

4.1.1 Estimation of land use requirements per sector

4.1.1.1 Requirements for agricultural land

Agricultural land requirements are given by an exogenous model for the European agricultural sector. The CAPRI model is a partial equilibrium, agricultural sector model, being composed of agricultural supply models at the level of administrative regions (NUTS2) and a global multi-commodity market model (Britz and Witzke 2014). Both models run in iteration until convergence of the commodity prices is found. CAPRI is ‘comparative-static’ simulating time steps independently of the previous ones. It is used to analyse the effects of agricultural, environmental and trade policies on agricultural production, farm prices and income, trade as well as environmental indicators. The supply model allows a detailed representation of EU policies, including endogenous modelling of greenhouse gas mitigation technologies. The market model simulates considers international trade and price changes in global markets. Potential interactions with non-agricultural sectors are not modelled and simulated as exogenous drivers.

Among the outputs of the CAPRI model, there is area of land in hectares required to produce the different agricultural commodities that are shown in Table 3.

Table 3. Mapping of CAPRI commodities to LUISA_BEES land use classes.

CAPRI commodity	CAPRI REGIO-CODE[13]	LUISA-BEES class
Cereals (wheat, barley, maize, rice)	ARAB	Arable
Oilseeds (rapeseed, sunflower)	ARAB	
Flax, hemp, tobacco, vegetables, fruits & other perennials, flowers	ARAB	
Fodder (maize, root crops, other fodder on arable land)		
Apples, other fruit trees, citrus fruit trees, grapes	PERM	Permanent crops
Olives (for oil	PERM	
Graze and grazing		Pasture
		Abandoned arable land
		Abandoned permanent crops
		Abandoned pasture

[13] Source: CAPRI documentation, p. 266, https://www.capri-model.org/docs/CAPRI_documentation.pdf

There is reference to “Abandoned” land use classes in Table 3. These are endogenous to the LUISA-BEES model. They have been introduced to account for shrinking of the in-use Agricultural areas in some regions. The land falls out of use and is left unproductive until required again. If it is not needed, it succumbs to natural succession, starting five years after abandonment.

The CAPRI .gdx files are read for the relevant scenario and processed using the rgdx.param from the gdxrrw package[14] in R. Demand files for agricultural land use are written in the format expected by the land use model. That the administrative boundaries within the CAPRI model are similar, yet not fully compatible with the EUROSTAT NUTS 2 codes used in LUISA-BEES. An internal mapping mechanism therefore compensates for the occasional differences.

4.1.1.2 Forest land use requirements

In most scenario cases there is no active demand for forest land because the demand for forest products is generally satisfied by adjustments in forest management practices or in fluctuations in trade, not in forest area changes. This does not mean that forest area does not change at all in the EU. Forest area has increased by 9% over the past 30 years (Forest Europe, 2020) due to socio-economic (abandonment) and the subsequent natural processes, and to active afforestation. 89% of the forest area and 92% of the biomass stock of EU-27 is available for wood supply (Avitabile et al., 2023). Thus, most of the forests in Europe are managed and for this reason, management intensity can vary according to the demand for wood. Relevant to the discussion to follow in this report: forest area may increase, it is not a given that the forests are in good ecological condition (Maes et al., 2020). The sequestration capacity of the forests will vary according to the age structure and species composition, among other characteristics of a forest such as the fluxes between forest carbon pools (including living biomass, dead organic matter and soils) (Grassi et al. 2021).

To ensure that the correct forest area is used in the start of the model simulation, we adjusted the Corine Land Cover map 2018 to match forest area reported in the FAO FRA 2020 reference statistics. The Forest Type map of Copernicus and the ESA GlobBiomass map were used to adjust the CORINE map, maintaining the MMU of the CORINE map. Also taken into consideration for future scenarios is the mapping of the forest available for wood supply (Alberdi et al, 2020). The ESA CCI Biomass map for 2017 was used to adjust the CORINE map as follows:

- The classes Broadleaved forest (311), Conifer forest (312) and Mixed forest (313) of the 2018 CORINE land cover map were aggregated into a single Forest class. The mean biomass density of each Corine forest polygon was computed using the ESA CCI Biomass map for 2017;
- The total forest area per country of the CORINE map (Broadleaved forest + Conifer forest + Mixed forest) was computed and compared with the Forest area reported by FAO;
- In the countries where the CORINE map presented a larger forest area, the forest was reduced by removing iteratively the CORINE forest polygons with the lowest biomass density, until the forest area matched the FAO statistics. The areas converted from Forest to Non-Forest in the Corine map were attributed to the class "Transitional Woodland / Shrub" (324);
- In the countries where the CORINE map presented LOWER forest area, the forest was INCREASED by adding iteratively the CORINE polygons classified as "Transitional Woodland" (class 324) and with the largest biomass density, until the forest area matched the FAO statistics. If the forest area was still smaller than the reference statistics after that all the Transitional Woodland class was converted to forest, the forest class was further expanded by adding iteratively the forest polygons from any other "non-forest" in the Corine map and with the largest biomass density. The areas converted from Non-Forest to Forest were attributed to the nearest Corine forest class (Broadleaved 311, Conifer 312, Mixed 313), where the distance was computed as Euclidean distance;
- The correction was done at polygon scale, maintaining as much as possible the minimum mapping unit of 25 ha of the CORINE polygons. Still, there are raster "objects" (groups of contiguous pixels) < 25 ha: these were in part already present in the original Corine map (raster

[14] https://rdrr.io/github/GAMS-dev/gdxrrw-miro/man/rgdx.html

version) and are due to the rasterization of polygons (which have a MMU of 25 ha). During the conversion of polygon to raster, distortions are inevitable and may form raster objects < 25 ha;

- The Corrected CORINE LC 2018 map used in the model matches at national scale the FAO forest area for 2018 (besides Iceland).

4.1.1.3 Urban land use requirements

Population projections are taken from EUROSTAT's EUROPOP[15]. They are treated in a way that they may actually populate different types of land uses. Population density evolves with time throughout the simulation, building upon an initial estimate of population density distribution. The evolution of population density is governed by a combination of the initial population density and the average densities in the immediate neighbourhood (Barbosa et al., 2015; Kompil et al., 2015). Once reaching a threshold of population density, the land is converted to the 'urban' land use class. Urban land may also be depopulated and converted to the "abandoned urban" class.

4.1.2 Allocation of land use requirements with LUISA-BEES

Land allocation in the LUISA-BEES model is based on the Dyna-CLUE model (Verburg and Overmars 2009). The allocation is discrete, meaning each unit of land, in this case each hectare, is assigned to a single land use type. What determines which land use type is allocated is a combination of the suitability of the land to host that particular land use type, and the demand for the land use type. The total suitability of land is the result of a combination of factors that express the added value of allocating land to a specific land use purpose. This is expressed as a coefficient. Each land use has a suitability map, which is the result of a set of physical factors, neighbourhood potential, transition costs, location-specific subsidies or taxes, and any physical restrictions on transition. These are time-dependant in the configuration and relate to "transitional" classes such as "young forest".

The demand files are exogenous to the model and are derived from different sources (Table 4).

Table 4. Land use classes in LUISA-BEES and associated sources of demand.

ID	Name	Source for demand
1	Urban	Population growth (EUROPOP)
2	Industry	Extrapolation of trends in industrial land expansion
3	Arable	CAPRI model output
4	Permanent crops	CAPRI model output
5	Pastures	CAPRI model output
6	Mature forest	The base map for forests (see section 4.1.1.2), is assumed to be Mature forest. Throughout the simulation, only 'Young forests' and 'Tree plantations' can evolve directly into Mature forest
7	Transitional woodland & burnt areas	Corine land cover for first year of burnt areas and transitional woodland. For modelled years: no burnt areas subsequently; transitional woodland results 5 years after agricultural land is abandoned.
8	Abandoned arable	Endogenous to model, when demand for arable land < actual arable land

[15] https://ec.europa.eu/eurostat/web/population-demography-migration-projections/population-projections-data

9	Abandoned permanent crops	Endogenous to model, when demand for permanent crops < actual permanent crop land
10	Abandoned pastures	Endogenous to model, when demand for pastures < actual pasture land
11	Abandoned urban land	Endogenous to model, when demand for pastures < actual urban land
12	Abandoned industrial land	Endogenous to model, when demand for pastures < actual industrial land
13	New energy crops	CAPRI model output
14	Semi-natural vegetation	Corine land cover for first year, no demand for this class but land may be taken from it
15	Young forest	Endogenous to model, no demand. Land becomes forest if formerly transitional woodland. Young forest is then converted to mature forest after 20 years
16	Infrastructure (ports, airports, roads)	Not modelled
17	Other nature	Not modelled
18	Salines, bogs and marshes	Not modelled
19	Water courses, lagoons and estuaries	Not modelled
20	Urban green	Not modelled

4.2 Changes in the land use model principles

As described above, the allocation in the land use model is discrete, meaning each unit of land, in this case each hectare, is assigned to a single land use category. What determines which land use type is allocated is a combination of the suitability of the land to host that particular land use type, and the demand for the land use type. The total suitability of land is the result of a combination of factors that express the added value of allocating land to a specific land use purpose.

By integrating the concept of ecosystem services in the model we have more flexibility to set goals in scenarios with respect to ecosystem services and can better assess the geographically-sensitive trade-offs of these. Furthermore, this approach will be capable of informing spatially-relevant policies at any scale (local, regional, national or EU) of nature restoration or protection laws, whose characteristic is to be spatially-explicit.

We begin with the implementation of the climate regulation ecosystem service, which is the core of this report with the development of a LULUCF module.

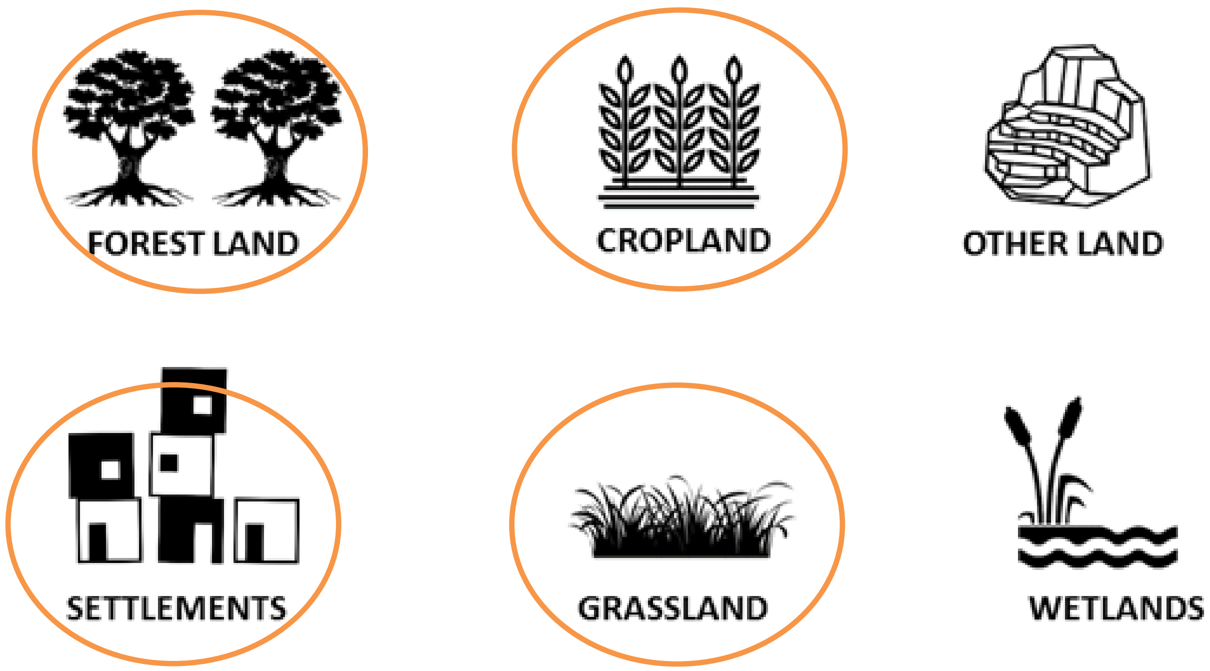
5 LULUCF module

According to the IPCC[16], the LULUCF sector covers anthropogenic GHG emissions and carbon removals that take place in the land use categories of *Forest Land*, *Cropland*, *Grassland*, *Wetlands*, *Settlements* and the residual *Other land* category. GHG emissions and carbon removals take place as a result of management and land use transitions among the categories (Figure 5), which lead to carbon stock changes in the three main carbon pools: living biomass, dead organic matter (deadwood and litter) and soil organic carbon (SOC). Net results need to be quantified in terms of emissions by sources and removals by sinks. Emissions of other non-CO_2 gases also occur under certain conditions following land use or land management changes that are covered under this sector (e.g., N_2O emissions from mineralization of soil organic matter).

For the purpose of our assessment, we focus only on quantifying carbon fluxes in living biomass resulting from land use changes or stable land use (not changes in land management). The implied emission factors, henceforth IEF (tonnes C/ha/ year), derived from national GHG inventories, can be used to approximate unit of carbon fluxes that result from a hectare of land use in transition. In short, IEF represents a country-specific aggregated emission factor attempting to capture all attributes and practices applied to a certain land use subcategory in the reporting country. IEFs are provided for both land remaining in the same category or converted to other land uses.

The net emissions or removals that result from carbon stock changes in living biomass and soil organic carbon are estimated based on the IEFs. These factors fluctuate over time due to the details of the land type being converted (eg young vs old forests), variability in management practices, natural disturbance and the adjustments of the implied emission factors by MS, which is based on updated land use change data over the window of the past 20 years, as shown in Annex 1. To capture this variability and define one single value for our forward-looking simulations, we calculated the average of the IEF values between 2010 and 2020 for each country and land use transition.

Figure 5. The LULUCF module currently considers transitions between four of six land use categories, as defined by the IPCC, 2006, these are circled.



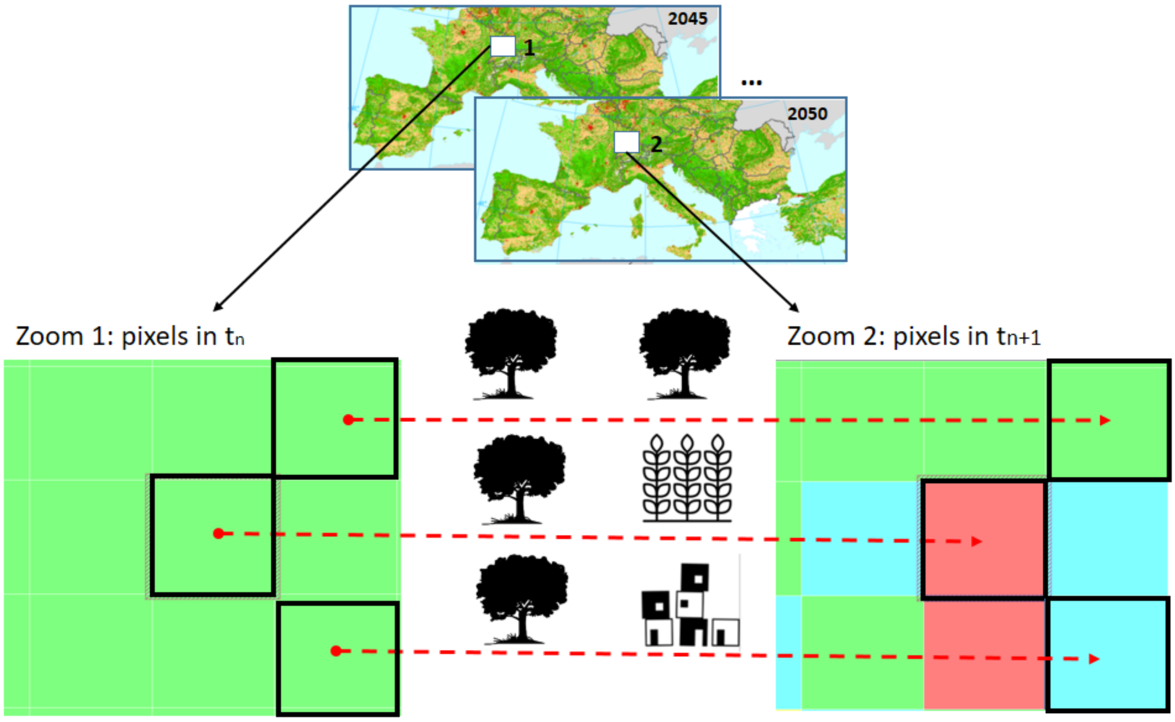
Source: IPCC, 2006

[16] https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

5.1 Pixel-level walk-through approach: general considerations

With every consecutive time step (t_n->t_{n+1}) of the land use model, the LULUCF module carries out a pixel-by-pixel comparison to record the transitions that have occurred (Figure 6). An IEF (tC/ha) is assigned to each land use transition , from where we derive associated CO_2 emissions/removals at pixel level.

Figure 6. Land use maps from LUISA-BEES in tn and tn+1. Maps are compared pixel-by-pixel to identify land use transitions in the time step (tn+1-tn).



Source: JRC, own elaboration

For each pixel, emissions/removals due to carbon stock change are calculated by Eq.1 :

$$\Delta CO2 \frac{tonnes}{ha} = -(\Delta C \frac{tonnes}{ha} * (44/12\ ))$$

where

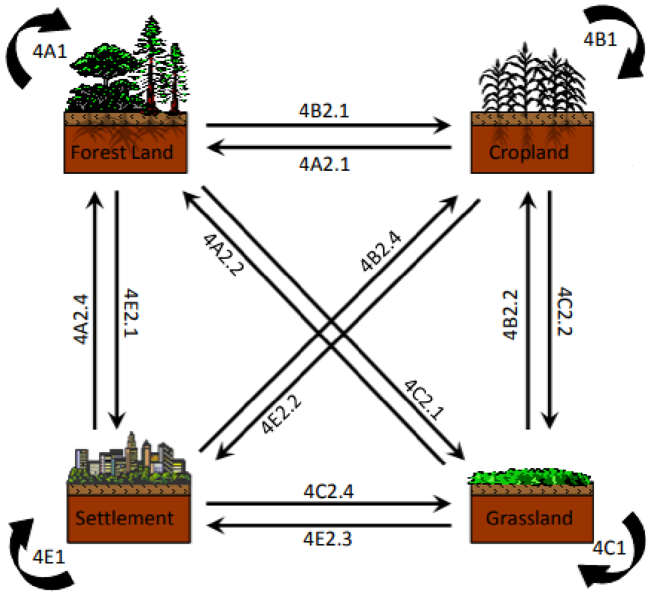
ΔC is the change in carbon stock from t_n to t_{n+1} , and 44/12 is the stochiometric relation of carbon/carbon dioxide) which allows for the conversion of one tonne of C into one tonne of CO_2 . The negative sign is applied so that reporting is made in negative emissions, where negative Δ CO_2 values means that carbon is removed from the atmosphere (i.e, $\Delta C > 0$) and positive Δ CO_2 that carbon is emitted to the atmosphere (i.e., $\Delta C < 0$).

The spatial dimension is mostly relevant here because of the future implementation of the soil compartment and the more detailed quantification of the forest-related conversions, as discussed further in sections 7.2 *Forest-related transitions* and 7.3 *Emissions from soil carbon stock change.*

5.2 Emissions from carbon stock changes in above ground biomass

The country-specific implied emissions factors (IEF) have been used in this application. IEFs are country and land use change-specific and are not constant over time because they are the result of dividing the total emissions by the activity area (see Annex 1). The land use conversions are shown in Figure 7:

Figure 7. Land use conversions for which implied emission factors are applied, with associated codes as defined in the IPCC guidelines.



Source: JRC own elaboration based on IPCC guidelines

The main land use conversions are between four land use classes that are modelled endogenously: Forest land, cropland, grassland and settlements. In the UNFCCC reporting, two other classes are considered: "Wetlands" and "Other lands", however the wetlands class is not modelled in the land use modelling platform yet, and the "Other lands" class accounts for a minor amount with respect to these four modelled classes and lack significant carbon contents. This class mainly includes bare soils, rocky outcrops and ice. The average value between 2010-2020 is used in the model for each of these conversions (Table 5). Missing data is either due to not observed, not estimated or unavailable data. These missing data are a major cause for uncertainty and overall quite problematic for future outlooks (see section 6.4, Discussion)

Table 5. Average implied emission factors for above ground biomass (2010-2020) per Member State, per land use conversion and land remaining the same (the column headings correspond to the conversion type, see Figure 7).

Party	A1	A21	A22	B1	B21	B22	C1	C21	C22	E1	E21	E23
AUT	-0.83	-4.47	-4.39	0.01	4.02	-0.18	NA	4.60	0.26	NA	2.69	-1.79
BEL	-2.38	-6.75	-7.02	0.00	15.28	NA	NA	37.36	NA	NA	18.74	NA
BGR	-1.79	-8.51	-8.05	0.03	NA	1.26	0.00	NA	NA	NA	20.50	0.71
CYP	-0.69	-2.88	-2.88	-0.54	2.93	0.17	-0.92	2.65	-0.17	NA	4.21	1.25
CZE	0.28	-8.48	-8.48	0.00	12.19	0.25	NA	13.79	-0.25	NA	15.26	NA
DEU	-3.94	-3.77	0.11	0.00	NA	0.76	-0.03	NA	-0.64	NA	2.47	-3.80
DNM	-2.36	-8.18	-9.13	0.02	4.66	-0.55	0.54	8.95	0.93	NA	12.68	0.37
ESP	-1.90	-4.10	-5.11	-0.07	1.74	-0.20	NA	6.21	NA	NA	5.56	0.57
EST	-0.91	-4.69	-5.18	0.01	NA	1.50	NA	8.63	-0.64	NA	20.84	0.92
FIN	-1.35	-4.07	-5.02	0.00	6.82	NA	-0.69	3.96	-0.02	NA	4.71	0.36
FRK	-1.87	-5.35	-4.23	0.01	16.14	0.33	-0.06	5.38	-0.15	0.10	14.56	1.27
GRC	-0.62	-3.43	NA	-0.05	NA	0.03	0.00	3.41	0.54	NA	1.83	0.93
HRV	-2.65	-1.89	-2.96	0.17	1.04	-0.36	NA	NA	0.56	NA	2.27	0.39
HUN	-1.55	-7.37	-7.47	0.01	3.89	-0.25	NA	9.15	0.19	NA	2.72	0.35
IRL	-3.38	NA	-10.68	-0.03	NA	NA	NA	9.62	NA	NA	11.45	0.47
ITA	-3.38	NA	-3.71	0.15	NA	1.28	-0.23	NA	NA	NA	16.30	4.80

LTU	-3.50	-5.52	-5.78	0.00	NA	0.32	NA	NA	-0.18	NA	NA	1.69
LUX	-3.11	-11.37	-11.13	0.03	11.84	0.14	NA	8.95	-0.22	NA	22.63	-0.44
LVA	-0.74	-0.95	-0.95	-0.03	2.23	NA	-0.21	1.60	NA	-1.65	6.49	4.62
MLT	-0.07	-0.20	-0.68	-0.17	NA	1.19	NA	NA	-3.01	NA	NA	0.44
NLD	-4.66	-13.05	-11.30	NA	22.78	0.69	-0.06	15.19	-0.76	NA	16.83	1.96
POL	-3.15	-2.10	-7.04	-0.13	NA	NA	NA	NA	-0.57	-0.09	23.56	3.02
PRT	-1.96	-7.08	-6.02	-0.06	2.84	-0.21	NA	1.35	0.17	NA	4.57	0.26
ROU	-3.49	-7.84	-3.76	-0.02	5.76	-1.03	-0.04	14.78	0.95	NA	38.79	0.35
SVK	-2.33	-5.69	-5.69	-0.72	4.62	0.15	NA	6.31	-0.02	NA	13.42	1.98
SVN	-1.49	NA	-4.72	-0.01	12.11	0.53	-0.88	7.80	0.64	-0.97	5.42	-0.39
SWE	-1.17	-4.73	-2.23	-0.08	13.26	0.33	-0.66	9.21	-0.43	0.00	7.67	-0.67

Important to note that for many classes, the IPCC guidelines (Tier 1) [17] assume that carbon stock changes in living biomass are in equilibrium, i.e., gains are fully offset by removals during the year (see Annex 2), therefore, the net carbon stock change in a given year for annual crops that remain annual crops is zero at Tier 1 level. given the marginal change in carbon stocks between the classes. To better capture the spatial variability and management practices of emissions across the EU territory, we opted not to consider IPCC default values and use the country-specific implied emission factors reported by the Member States in their GHG National Inventory Report (NIR).

[17] https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch05_Cropland.pdf

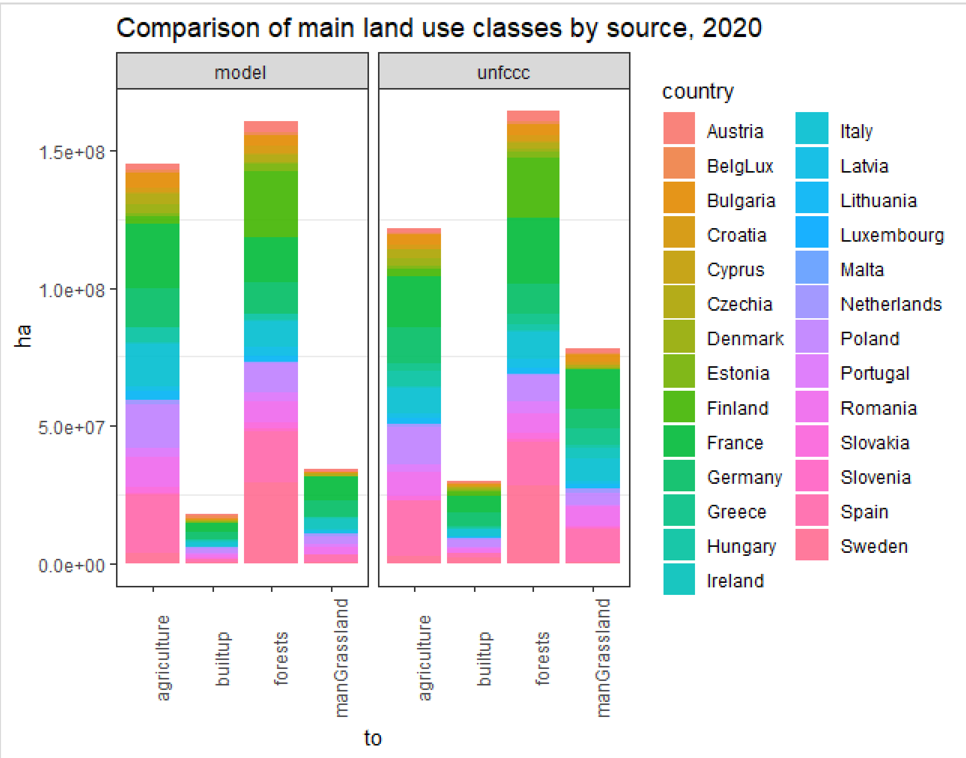
6 Results

The land use model was configured for a basic business as usual scenario, using a 2012 land use map as a starting state with an end state of 2020 to be able to compare results with the UNFCCC records for the same year. The model computed an average of – 334 MtCO2 eq per year for a 5-year period starting in 2015. This is much higher (i.e. mitigation is higher) than the UNFCCC value reported of -258.48 MtCO2 eq (for the land use conversions considered in this report, and excluding the French overseas territories). This latter value is of course in line with expectations (as they are the reported values). In this section we identify the main reasons for this global difference between the two sources. The exercise exemplifies the difficulties of estimating GHGs in the land sector by using as a metric a (given) unit of carbon by hectare assigned to a land use class.

6.1 Differences in land change estimates

The Implied Emissions Factors (IEFs) as reported in 2022[18] are multiplied to the hectares of land that undergo a transformation or that persist in time- As shown in Figure 8, there are discrepancies between the land transitions reported in 2022 for 2020, and the model output. The model shows a higher land area associated to agriculture, while UNFCCC shows a higher land use area associated to built-up, forests and managed grasslands. There could be many reasons for these differences. It is important to note that the land use model uses the 2018 Corine Land Cover (CLC) map as the basis, and that this map has 45 classes. Therefore the discrepancies may be due to the aggregation of the land use classes. Examples of classes that may be included or not in any of these major land use classes are transitional woodland, mixed agricultural land classes and classes that may or may not be considered as "built-up" such as mining. Since both the CLC and the UNFCCC are validated at national level, a good allocation of these sub classes to the main classes shown here would have to be done at national level with the experts who are preparing the reporting.

Figure 8. Total land use area of the main land use classes for the EU, as computed by the model and the UNFCCC declarations.

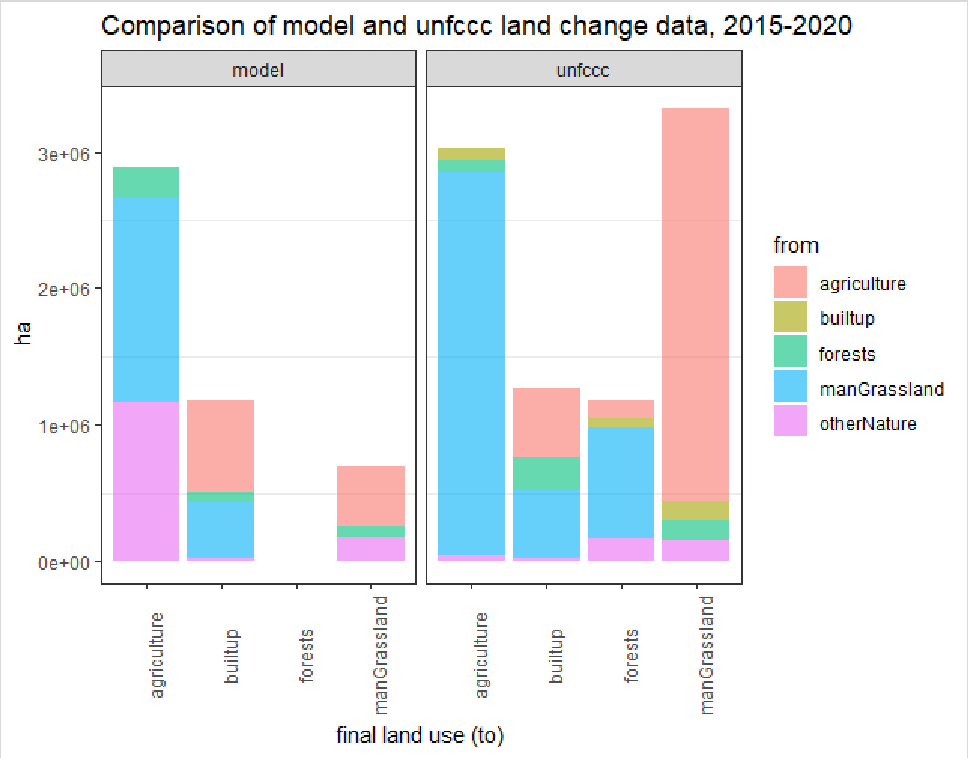


Source: JRC own elaboration

[18] https://unfccc.int/ghg-inventories-annex-i-parties/2020

When comparing the land use categories that are transformed to other categories during the five-year time period between 2015[19] and 2020[20] in the EU, it is clear that there are many differences between the two tools (modelling and reporting). The modelling tool does not consider it possible for land to be converted to forest within a five-year period (hence the bar under the forest class is empty in Figure 9 for the model output), while UNFCCC data shows roughly one million hectares converted to forests during the five year period. Figure 9 gives an overview of the issues to address in aligning the model output to the UNFCCC reporting.

Figure 9. Comparison of model allocation from main land use classes to the main land use categories.



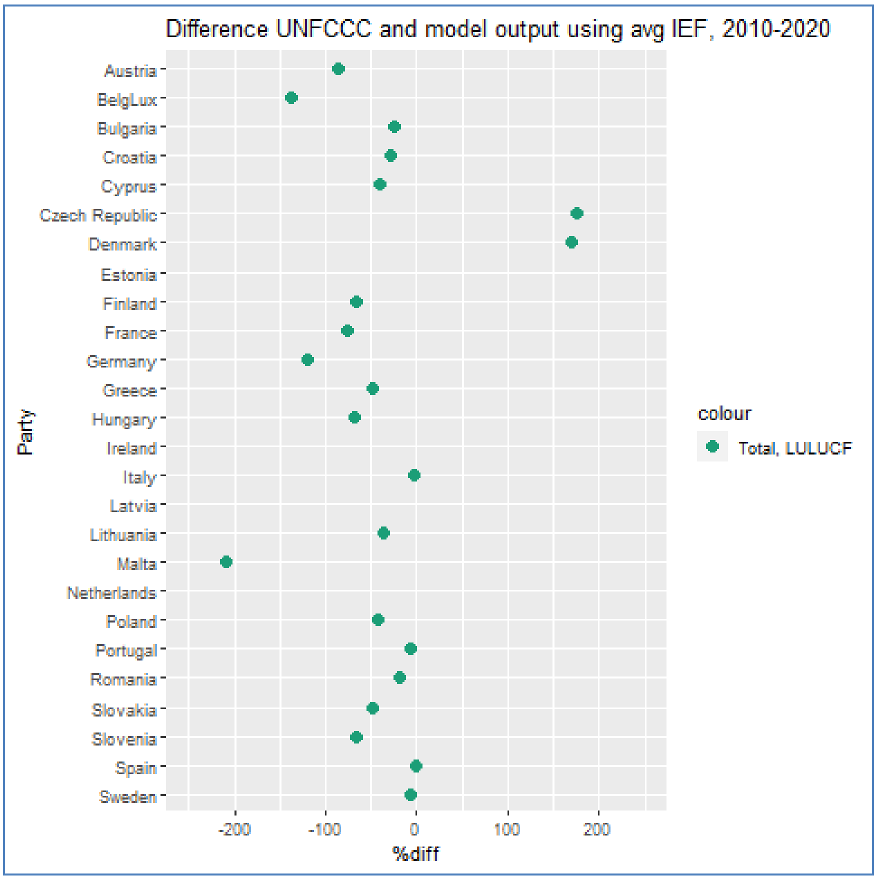
Source: JRC own elaboration

[19] For this simulation the 2012 CLC data is used as the starting date in the model
[20] Thus reading 2016-2020 data from UNFCCC, because 2016 data is reported as the change since the previous year, 2015

6.2 Differences in emissions estimates

The first results of the LULUCF module in the LUISA-BEES model show a strong variability between countries in terms of agreement with UNFCCC reporting for 2020 (Figure 10).

Figure 10. Comparison of the whole LULUCF sector 2020 emissions from land use change between model output and UNFCCC declarations (countries with no data point are outside of thresholds).



Source: JRC own elaboration

The percentage difference was computed as absolute difference between the two datasets, divided by the mean of the two. The actual values are shown in Annex 2.

As shown in the figure, the vicinity between the model estimates and the UNFCCC reporting for the emissions from the total LULUCF sector varies between countries. In the following sections we assess the reasons behind the deviations.

6.3 Analysis of discrepancies at national level

A number of reasons explain the discrepancies between the model results and the UNFCCC reporting. Given the UNFCCC reporting in CRF tables, the IEF values are derived by the division of total emissions and activity data reported by the country. This approach makes it a simple average that disregards the actual inputs and usually consists in multiple and area-unbalanced land subcategories, each one with different emission factor.

We have identified five broad categories for the large deviations between the model results and the UNFCCC reported values:

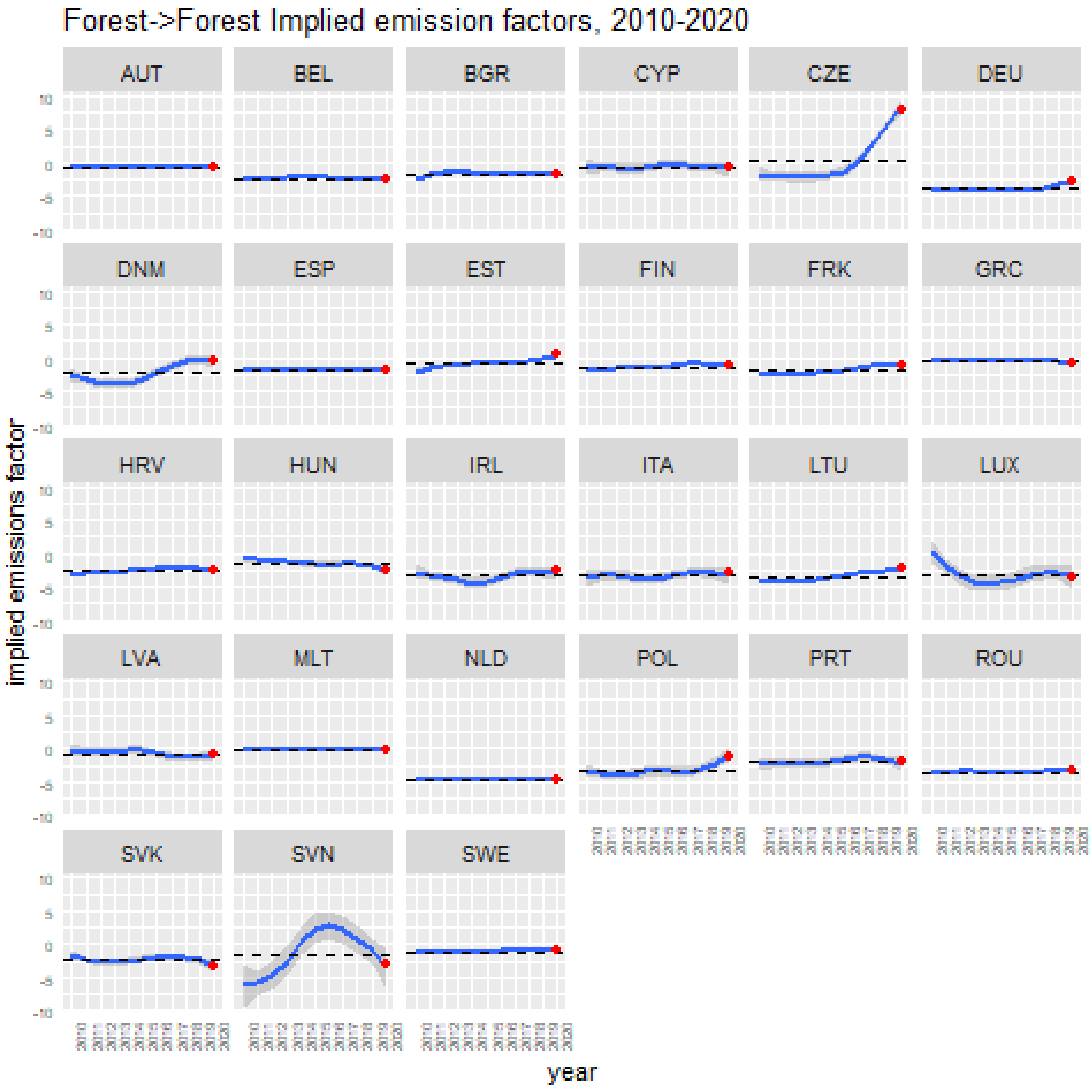
1. The IEF averages used in the model do not reflect the 2020 EF used to compute the UNFCCC reporting and in those 10 years, there are strong signals;
2. Forests can never appear from one year to the next in the model;

3. Differences in aggregation and definitions of land use classes;
4. "Other land" and wetlands not considered in model;
5. Other country-specific reporting situations such as non-CO2 emissions, emissions from drainage and rewetting (also CO_2), biomass burning (also CO_2).

6.3.1 Variations in IEF values

Because of the way the IEFs are computed, there is a high fluctuation in these coefficients, in particular for the forests. This is an important limitation of the current approach of using IEFs to estimate emissions for the category Forest land remaining forest land, which is a substantial amount of land in Europe and therefore impacts the results considerably. In some cases the positive emissions are consistent with the time series of the country, while in others there may even be a reversal in sign, from a sink to a source of GHG emissions, throughout the time series (Figure 11). The other land use change combinations are shown in Annex 1.

Figure 11. IEF values for Forest land remaining forest land for EU Member States. The figures below show the smoothed trendline with variation over time represented by a grey shaded area. The red dots represent the IEF declared in 2020 while the black dotted line represents the average value between 2010-2020.

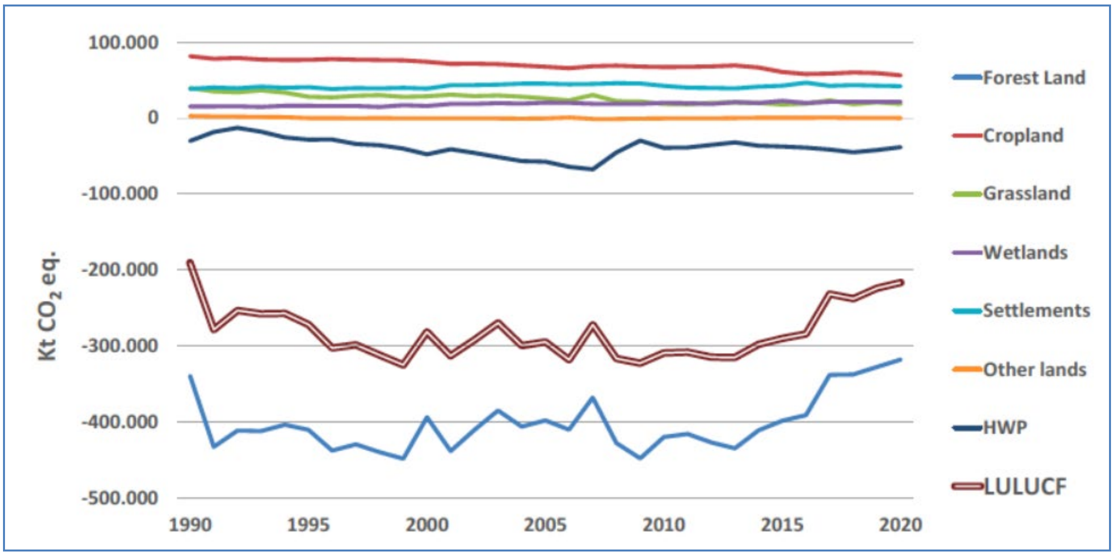


Source: JRC own elaboration

6.3.2 Forests

Forests are the most significant contributors to the overall LULUCF budget (Figure 12), and as shown above, they can also be volatile.

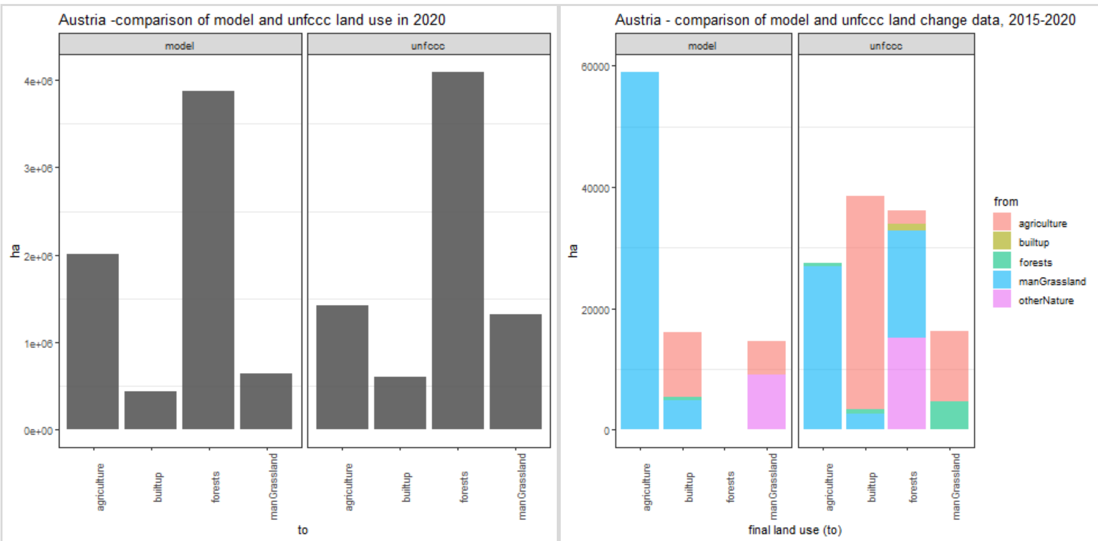
Figure 12. The contribution of forests to the overall LULUCF sector.



Source: G Grassi, personal communication

Forests are simulated to undergo a slow growth in the model so the "A2.x" transitions will never occur from year to year in the model in a 5-year time step (see Table 4), but in UNFCCC reporting they do. As shown in Figure 13, while the overall land use is comparable in 2020 between the model and the UNFCCC reporting (left), no new forest land appears in the model between 2015-2020 but it does in the UNFCCC reporting (right). See Annex 4 for comparisons of other countries. Suggestions for improvements using a specific model for estimating carbon in the different pools in forests are discussed in section 7.2 *Forest-related transitions*.

Figure 13. Comparison of total land use by category (left) and land use change dynamics (right), for the model and the UNFCCC reported for Austria.



Source: JRC own elaboration

6.3.3 National level discrepancies in land change estimates

Probably the most important reason for discrepancies between the modelling outcome and the UNFCCC reporting is the overall land use change estimates do not match. This may be due to differences in aggregation and definitions of land use classes. Particularly problematic is grassland, so the overall land use change between 2015-2020 as estimated by the model vs the UNFCCC declarations do not match. National level comparisons between UNFCCC reporting and the LUISA-BEES model confirm what is seen at EU-27 level: Grasslands and agriculture land are the main cause for discrepancies. Just as Figure 8 and Figure 9 show that the land area is higher for the land category "managed grassland" in UNFCCC with respect to the CLC equivalent, pasture. The national-level data shows differences to varying degrees (see Annex 4).

Some notably strange reporting occurs where, for example, settlements are registered as converting to forest, agriculture and / or grassland. This occurs in Austria, Latvia, Germany, France, Finland, Sweden, Netherlands, and is most pronounced in Czechia. While it is conceivable, the land use model is configured to render this transformation extremely costly and furthermore, must first go through an "abandonment" phase (see Table 4), and it therefore does not occur in any country. According to the UNFCCC tables, the reverse also happens (forests and agricultural land and grassland are replaced by settlements)

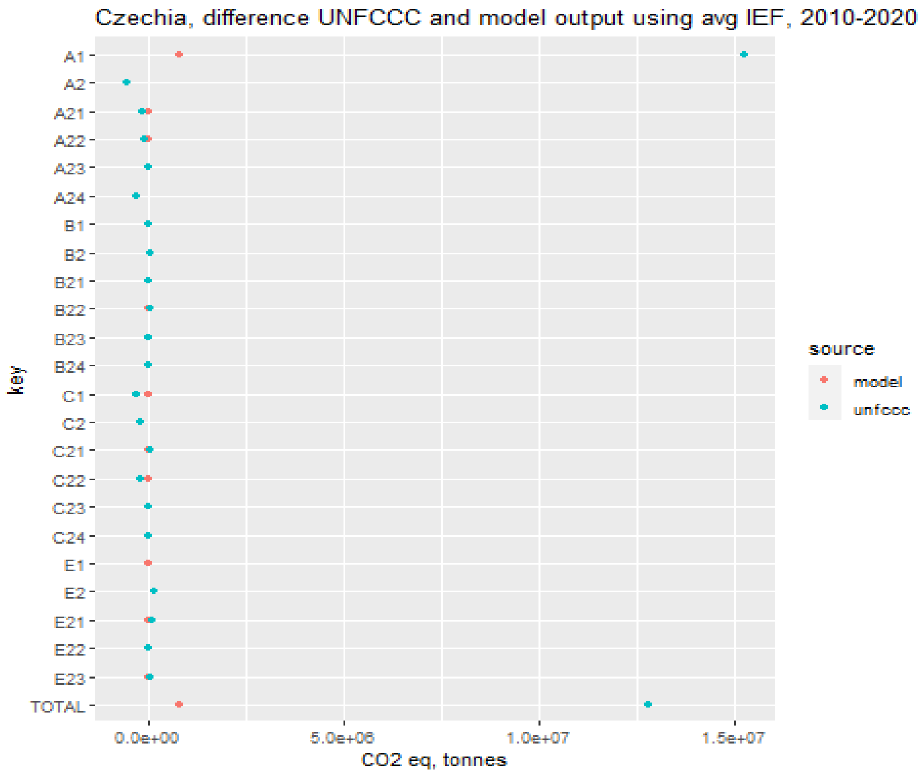
6.3.4 Wetlands and other land

The model does not take wetland and "other land" into consideration yet (see Figure 7).

6.3.5 Specific cases

While each country has its specificities, we highlight Czechia. This country was reporting negative emissions until 2017. The authorities have confirmed that this is due to increased harvest levels due to salvage logging operations, which took place because the extreme heat and drought have made their forests vulberable to unprecedented pest attacks. In the case for Czechia, the emissions estimated by the LULUCF model are quite similar to the UNFCCC reporting, with the exception of the massive difference in class 'forests remaining forests' (Figure 14). This difference is important enough to throw off the whole LULUCF sector estimate. While it is clear that for Czechia, this is likely due to the loss of biomass in Czech forests due to natural disturbances. All comparative graphs are shown in Annex 5.

Figure 14. Emissions for each land use change combination as reported in UNFCCC by Czechia in 2020, and as computed by the LULUCF module for Czechia for one year (avg 2015-2020).

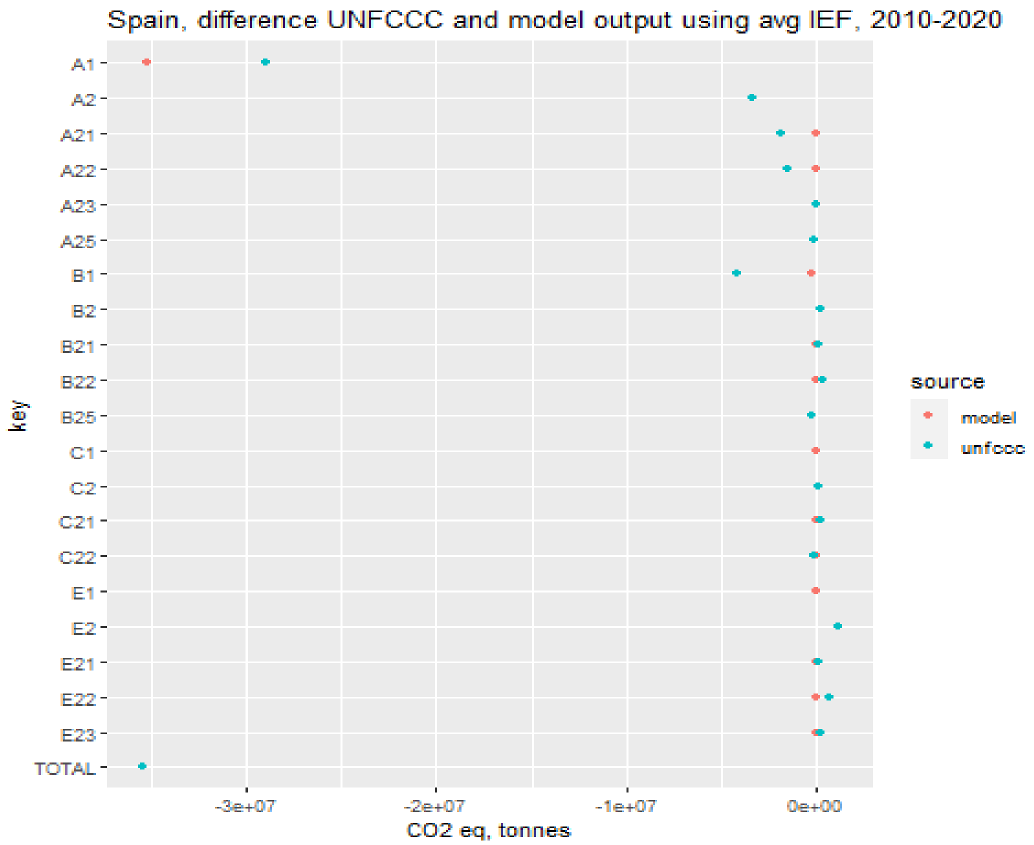


Source: JRC own elaboration

6.4 Characteristics of matching countries: Italy, Portugal, Spain and Sweden

The case of Spain was selected because of the close results between the land use model LULUCF module and the UNFCCC reporting (-35,496,032 model vs -35,558,488 tCO_2 eq / year UNFCCC reporting). The main discrepancies are in the classes forests remaining forests (A1), followed by discrepancies in crop to forests (A21) and grassland to forest (A22). The model overestimates the negative carbon emissions for class A1, but underestimates for classes A21 and A22 (Figure 15), explained by the latency in the model to actually convert land to forests. The model does not allow land to be converted to forests from year to year because it simulates the slow growth of forests.

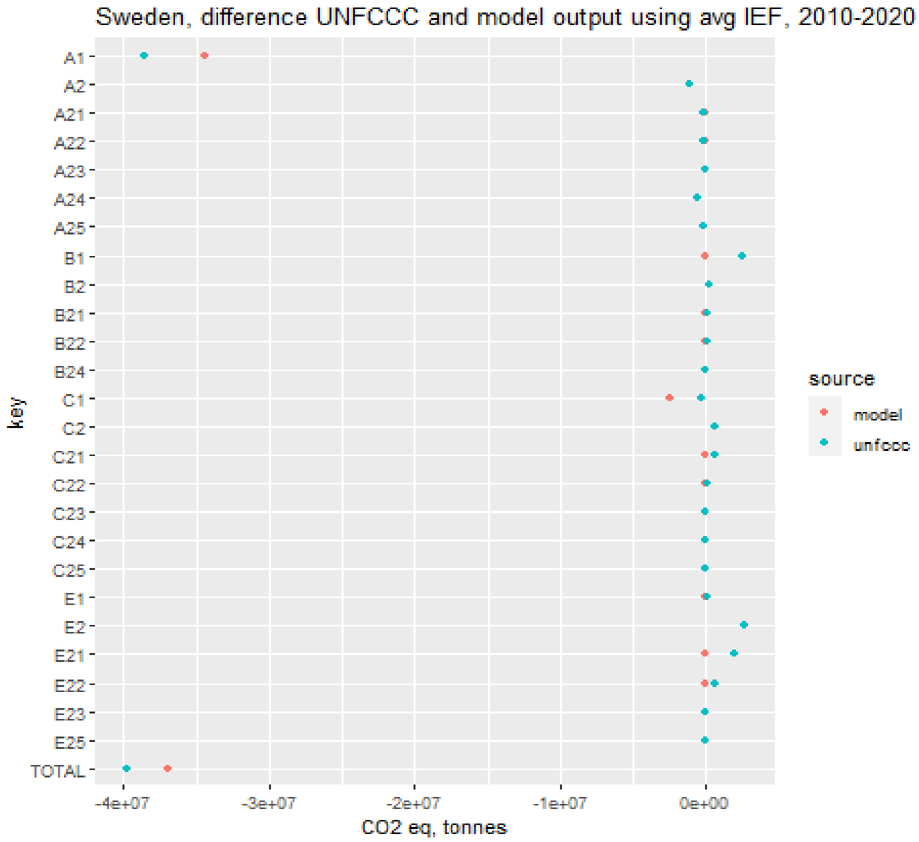
Figure 15. Emissions for each land use change combination as reported in UNFCCC by Spain in 2020, and as computed by the LULUCF module for Spain for one year (avg 2015-2020).



Source: JRC own elaboration

The main discrepancies for Sweden, another country where are in the classes forests remaining forests (A1), followed by discrepancies in crop remaining crops (B1) and grassland remaining grassland (C1). The model overestimates the negative carbon emissions for class A1, but underestimates for the persistence in the crop and grassland classes, and furthermore, does not capture the emissions associated to the conversion from forests to settlements. This unlikely conversion (E21) is in fact very expensive according to the land use model, and therefore hardly occurs, however is reported in UNFCCC (Figure 16).

Figure 16. Emissions for each land use change combination as reported in UNFCCC by Sweden in 2020, and as computed by the LULUCF module for Sweden for one year (avg 2015-2020).



Source: JRC own elaboration

7 Discussion and way forward

The development of a LULUCF module as a first ecosystem service to be implemented in the LUISA-BEES land use model was a valuable exercise that raised questions about the land use classification and transitions themselves, both as they are configured in the land use model, as well as how they are reported in UNFCCC. Analysis of the UNFCCC transitions put into evidence unlikely transitions such as built-up land to forests within a 5-year time period, as well as incongruencies in definitions and land use class aggregation to the IPCCC categories between the two sources. Particularly problematic is the mapping of the CLC classes to agriculture and grassland categories. In terms of philosophical differences, the model does not allow for forests to appear when land is abandoned and natural succession creates new forests. In this test scenario there is no active forest plantation.

Furthermore, the way that afforestation and deforestation are handled could be much improved with our knowledge of the standing (above ground) biomass and the carbon budget of forest, which includes compartments underground. Soil carbon is in fact an important part of this work that has not yet been implemented. In this section we discuss the aspects of the model that can be improved.

7.1 Improvement of coherence, land transitions

Although there are many ways that the LULUCF module can be improved, the priority must be on understanding and accounting for the differences between the model output with respect to the UNFCCC reporting and taking a conceptual decision on how to handle these discrepancies. Although it is clear that the reporting has a different objective with respect to scenario-building exercises for land use change, the model outputs are not useful for real-world comparisons if they are not globally similar to the reporting, and this relies on comparable land use transition matrices. Throughout this exercise, it has become clear that the goal should not be to mimic the UNFCCC reporting, as the reported data is not possible to anticipate given the complexity in the national-level monitoring schemes, their updating and the way the IEFs are computed in the first place.

As shown in Annex 5 and Figure 12, the main differences are made in the forest land remaining forest land category, followed by other forest-related categories. For this reason we suggest two focus areas for future work: 1) Improve forest-related transitions; 2) Include the soil compartment.

7.2 Forest-related transitions

For future assessments, we propose to use IEF for non-forest-related transitions and rely rather on JRC's datasets and modelling for forest-to-forest, deforestation and afforestation land use categories. The reasons for this are principally because:

1. Forests are the driver of the overall sink in the sector and merit therefore more in-depth attention, in particular for scenario work where forests may increase in area, deteriorate or improve in condition, be impacted by natural disturbances etc. More detailed emissions estimates based on the forest age structure and species composition should therefore be used;
2. Natural disturbances have a strong impact on the IEF, making the average IEF a poor estimate of forest remaining forest emissions;
3. In the case of deforestation, the amount of standing biomass at the time of deforestation is important to consider, the national averaged IEF cannot provide this level of detail;
4. Attributing one IEF for whole countries for this land use conversion is not informative (see Annex 1 graphs showing temporal variations in IEF for forest-land conversions for the countries).

7.2.1.1 Forest land remaining Forest land

The land use subcategory "forest land remaining forest land" is one of the main drivers of the LULUCF sector and the way countries manage their forests plays an important role on the overall carbon budget of the land-based sector (see Figure 12). Forest management implies the permanence of the forest land and its maintenance through a sustainable use of wood (harvesting) and other resources, taking into consideration forest ageing, structure and species composition.

Land use modelling often lacks a proper representation of forest management, merely classifying "forest" as single category without detailing harvesting, ageing and regrowing stages, thus increasing the uncertainty in the estimation of CO_2 emissions and removals. To overcome this limitation, we could include the estimates of all compartments using the Carbon Budget Model (CBM-CFS3).

The CBM-CFS3 model, developed by the Canadian Forest Service (CFS), can simulate the historical and future stand and landscape-level C dynamics under different scenarios of harvest and natural disturbances (e.g. fires, storms), according to the standards described by the IPCC. CBM is an empiric model running on spatially referenced data (e.g., strata, defined at country or regional level, depending by the available data sources) (Kurz et. al., 2009, with CBM databases adapted to EU conditions, Pilli et al., 2018). It is currently applied to 25 EU Member States, both at country and NUTS2 level (Pilli et al., 2016a, 2016b, 2017, 2018). CBM runs with annual time steps , and the most recent applications can also combine different climate scenarios with various forest management strategies (Pilli et al., 2022).

Based on the model framework, each forest stand is described by area, age and land classes and up to 10 classifiers based on administrative and ecological information and on silvicultural parameters (as forest composition and management strategy). A set of yield tables defines the merchantable volume production for each species while species-specific allometric equations convert merchantable volume production into aboveground biomass at stand-level (tC/ha). The model provides data on the net primary production (NPP), C stocks and fluxes, as the annual carbon transfers between pools and to the forest product sector with an annual time step.

The model could be used in this framework in the same way it is used in Pilli et al (2016) and Sahoo et al. (2021), whereby three degrees of harvest levels are pre-processed in the CBM model (Business As Usual, which is based on historical harvesting levels; -20% and +20% harvest levels). The results could then be used as look up tables in the land use model to estimate the carbon sink for all pools according to the selected scenario.

7.2.1.2 Afforestation

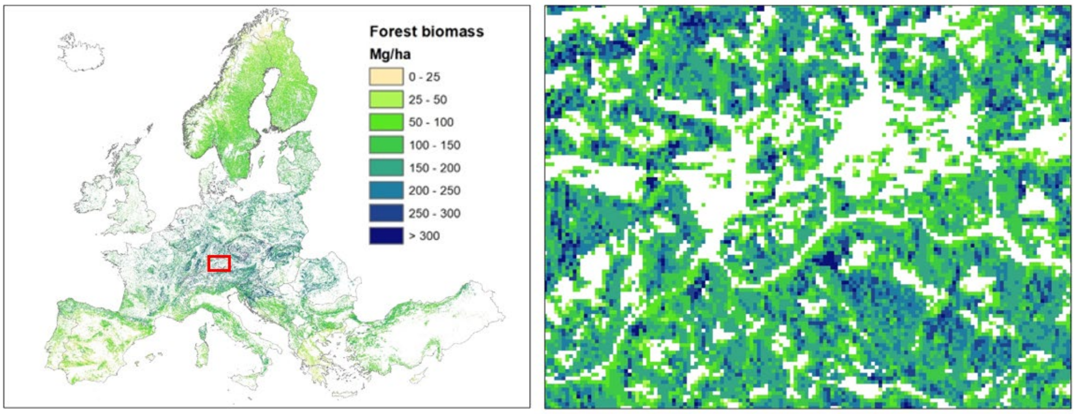
Similarly to the solution outlined above for Forest land remaining forest land, the Carbon Budget Model could be used to simulate the accumulation of carbon in the different pools with the accumulation of forest biomass on land that was something else prior. The look up table solution would also apply as suggested above, however assumptions to be taken on the forestry type that takes over the land is not trivial and should be relevant to the site where the afforestation takes place.

7.2.1.3 Deforestation

The transition from forest to any other land use category (e.g., cropland or grassland) is considered as deforestation. This means losing all the carbon content in forest living biomass at once according to the Tier 1 method (see Annex 3). This instantaneous oxidation approach does not take into account the carbon stored into Harvested Wood Products (not directly emitted to the atmosphere) nor the potential carbon accumulation in the vegetation of the final land use category. This approximation makes sense whenever detailed EFs are not available, since the loss of carbon due to forest clearing is much higher that the carbon gain in the final land use class within the 5-years' time step.

The starting point to assess the emissions associated to deforestation would be given by the EU biomass map (Avitabile et al., in prep.), which provides the forest aboveground biomass density (Mg/ha) of dry matter with a pixel resolution of 1 hectare for the reference year 2020, the most recent data on EU forest biomass content (Figure 17). The biomass definition employed in this map includes all aboveground biomass compartments of the living trees, namely the aboveground part of the stump, the stem from stump to top, dead and living branches, and foliage. The map matches the reference national statistics harmonized in terms of forest area and biomass definition, synchronized to the same reference year (2020) using the Carbon Budget Model (see Avitabile et al., in prep.). The biomass map is converted to C units (MgC/ha) by using a conversion factor of 0.47 (IPCC, 2006).

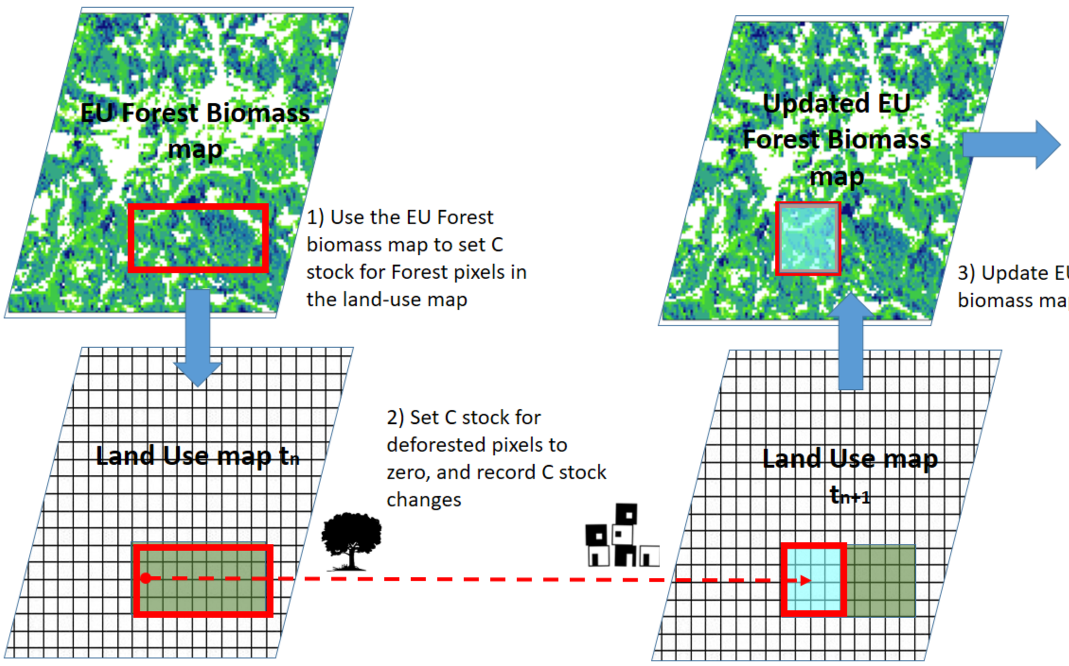
Figure 17. EU forest biomass map 2020 (Mg/ha). Raster map with 1ha pixel resolution.



Source: Avitabile et al., 2023

A forest pixel in the initial land-use map t_n (e.g., 2020) would be assigned a biomass carbon content based on the value of the same pixel in the EU biomass map (Figure 18). We consider the transition from forest to any other class as deforestation; the carbon stock of deforested pixels is assumed oxidized and transferred to the atmosphere at the time of the deforestation and the carbon content would therefore be set to zero in the final land-use map t_{n+1} (e.g., 2025). The resulting carbon stock change (t_{n+1}-t_n) is recorded. Subsequently, the EU biomass map is updated to t_{n+1} with the new pixel values (in the example, pixels change land use category from forest to settlements with zero carbon content), becoming the new reference EU forest biomass map for the next time step.

Figure 18. Pixel walk-through for the deforestation case.



Source: JRC own elaboration

Figure 18 shows the pixel walk though for the deforestation case. The EU Forest biomass map is the starting point to define the biomass carbon content of each forested pixel in t_n. Initial (t_n) and final (t_{n+1}) land use maps from LUISA-BEES are compared pixel-by-pixel to record land use transitions and calculated biomass carbon stock changes in the time step t_{n+1}-t_n. Deforested pixels in t_{n+1} have a biomass carbon content equal to zero (100% C loss). These new values are used to update the EU forest biomass map in t_{n+1} for the next time step, and cleared pixels are not considered as forest anymore.

7.2.1.4 Summary table

Table 6 summarises the approaches adopted to estimate carbon stock changes for each land use transition.

Table 6. Summary of main methodological approaches used to estimate C stock change for forest land transitions.

Transition	Approach	Data
Forest-to-Forest (forest management)	Carbon accumulates in the forest with time as result of forest growth, use and natural disturbance. Results from the CBM under 3 scenarios of forest management to estimate the sink	CBM model output to build look up tables representing three harvest levels for the period 2020 -2050: business as usual as reference, also assuming a constant afforestation rate, +20% harvest compared to reference, combined with an increasing afforestation rate (+20% in 2050, compared to 2020), and -20% harvest compared to reference, combined with a decreasing afforestation rate (-20% in 2050, compared to 2020).
Other land uses-to-Forest (afforestation/reforestation)	Carbon gains and losses in living biomass are estimated. Complete afforestation (i.e return to original state) and partial afforestation processes can be simulated	CBM model output to build a lookup table. These can be species-specific and country-specific
Forest-to-other land uses (deforestation)	This transition is considered as deforestation with a loss of 100% of living biomass carbon stock. The 2020 EU biomass map is the starting point for the assessment of carbon stock changes; the map is updated every 5 years according to land use transitions at pixel level	Living biomass carbon stock change from the 2020 EU biomass map – loss of 100% of carbon stock in deforested pixels

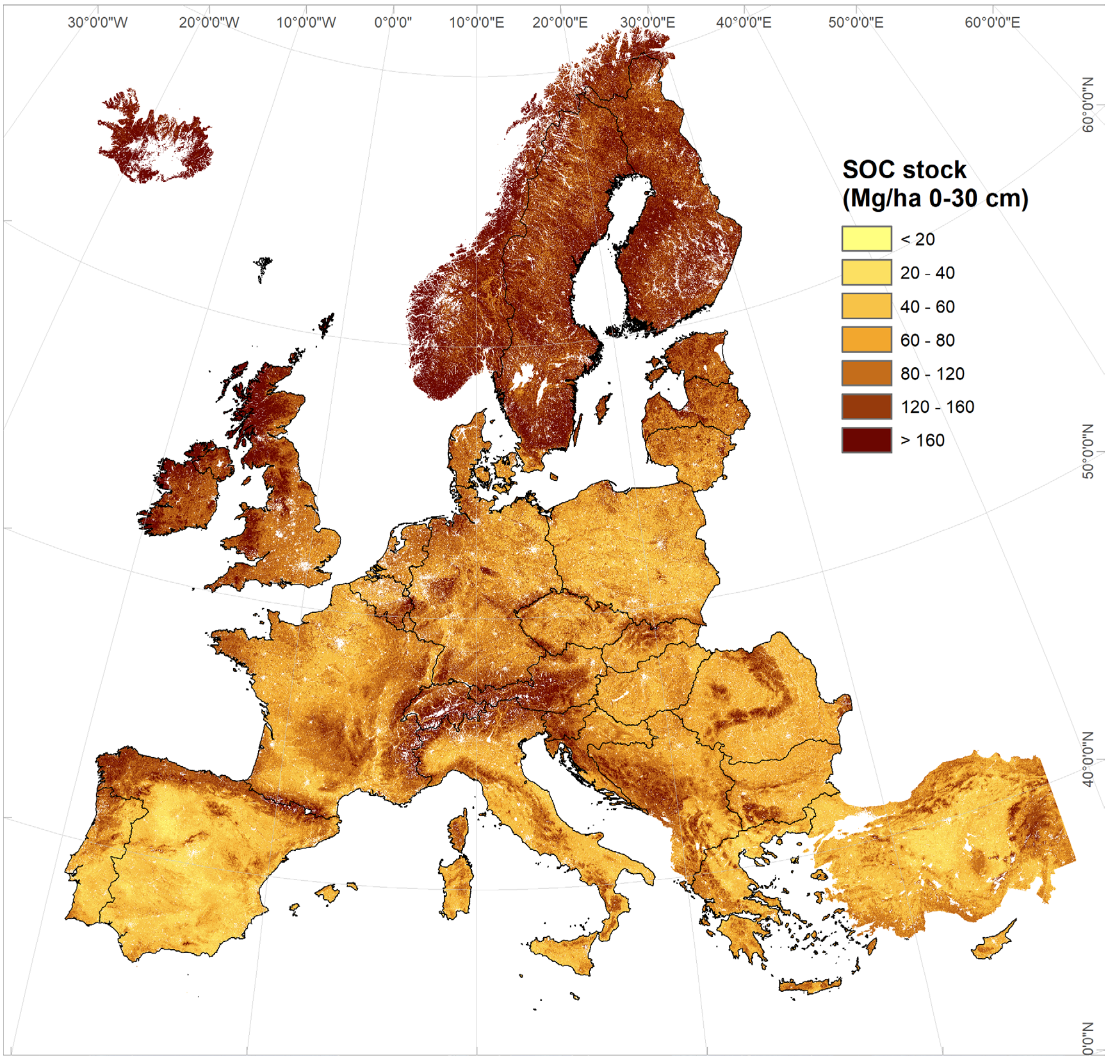
7.3 Emissions from soil carbon stock change

Soils are the largest store of carbon in terrestrial ecosystems, and in the EU, the highest soil carbon density is in coniferous forests (Lugato et al, 2021). Land cover and land use changes affect the soil organic carbon content (SOC) and consequently CO_2 emissions or removals from soils. According to IPCC rules (AR4, 2006), soil carbon stocks reach equilibrium after 20 years on average, meaning that the net CO_2 exchange to the atmosphere is zero after this time frame. Emissions or removals from soils occur as a consequence of land use changes. Therefore, a pixel persisting in the same land use category from 2020 to 2050 will not emit or remove CO_2. In the model, when a land use change is observed, the soil starts emitting (or removing) for the following 20 years before reaching the equilibrium, if no further land use change occurs and when more than one land use change occurs, emissions are recalculated.

7.3.1 Soil carbon stock changes: a spatially-explicit approach

The Land Use and Coverage Area Frame Survey (LUCAS) is the largest soil survey in Europe (Orgiazzi et al, 2018) The LUCAS point data can be used to generate a look up table of the soil organic carbon per climatic unit and land use/land cover and soil type (Figure 19). The map of soil organic carbon can be used as a benchmark to represent the SOC content for the start of the simulation and could represents the soil carbon content in the reference period 2009-2015 (Fernández-Ugalde et al, 2020; Panagos et al, 2020).

Figure 19. Soil organic carbon map.



Source E Lugato, personal communication

To define the soil carbon stock change for this transition, we may use the look up table previously calculated for each climatic unit, soil type and land use class to derive emission factors from the look-up table.

In this approach, the SOC change is considered to be more related to baseline content dC = Cbase * EFluc (tn+1) .

By using this method, we are able to better represent the spatial variability of soil carbon stocks across the EU. The new formula to estimate ΔC is therefore:

$$\Delta Cs \frac{tonnes}{ha} = C(\mathrm{tn}+1) - C(\mathrm{tn})$$

and the associated emissions are:

$$Soil\ CO2\ emissions\ (\mathrm{tn}+1-\mathrm{tn}) = -\frac{\Delta Cs*(-44/12)}{20years} * 5\ years$$

The soil starts emitting (or removing) for the following 20 years, if no further land use changes happen. When more than one land use change occurs in the same pixel, we recalculate emissions (or removals) for each time steps.

7.4 Ecosystem condition

Ecosystems with appropriate extent and in good condition are able to provide higher flows and more services than fragmented and degraded ecosystems. This is the framework established in the System of integrated Environmental and Economic Accounts (SEEA), whose module on Ecosystem Accounts (SEEA EA) has been adopted as standard by the United Nations Statistical Commission in March 2021 (UN, 2021). The JRC is working on improving their understanding of the relationship between ecosystem services and ecosystem condition (La Notte et al 2022).

Ecosystem properties and condition reflect the type of ecosystem as result of a specific land use. Therefore, a cause-and–effect relationship can be established between land cover and land use, ecosystem condition and ecosystem services. This relationship can be established by investigating the measurements and indicators whose change determines modifications in each step of the modelling procedures. For example: the land use affects imperviousness, which is a condition indicator and is also a variable to estimate the flood control service; agricultural use is the main diffuse source for nitrogen emissions whose concentration is a condition indicator but emissions themselves are also the key variable to estimate the water purification service. Any land transformation (e.g. from forest to cropland or from cropland to urban sprawl) that will increase imperviousness or nitrogen emissions will directly affect, through a modified condition of the ecosystems, the delivery of these two services.

This kind of analysis needs to be undertaken for each ecosystem type (in terms of condition) and for each ecosystem service. There are in fact ecosystem features and ecological characteristics that cannot be generalized for the cause-and-effect relationship to be effective.

7.5 Conclusions

Complex systems such as land systems cannot be fully represented with models, but they may help us to tell useful stories about complex problems. The broad nature of the European Green Deal, and the varied means by which to achieve many of the goals therein through the bioeconomy, forces us to ensure that the impacts of a green transition are at least known. The series of changes to equip a land use model to address some of the most pressing questions we have associated to green transition, such as what the impacts of additional biomass removals are and uses on land and the ecosystem services they provide, requires us to re-work our models to include concepts such as ecosystem services. To assess the trade-offs, the ecosystem services have to be well represented in the model. In this report, we focus on the development of a LULUCF module for climate regulation as a first ecosystem service.

The general approach presented here was to multiply the average of the Implied Emission Factors from 2010-2020, as reported by Member States in 2022, by the area of land use and land use change. The model was run for a period of 8 years, from 2012 to 2020 to be able to compare the results to the reported values of emissions from the LULUCF sector for 2020. Results showed that there were discrepancies between the two sources, and that the main reason for the different results is the forest land remaining forest land for two main reasons: The IEFs are fluctuating from year to year within the countries for various reasons; and the land use and land use change area is also different and by using an average IEF over 10 years, the IEFs are different from the mainly due to land use change area.

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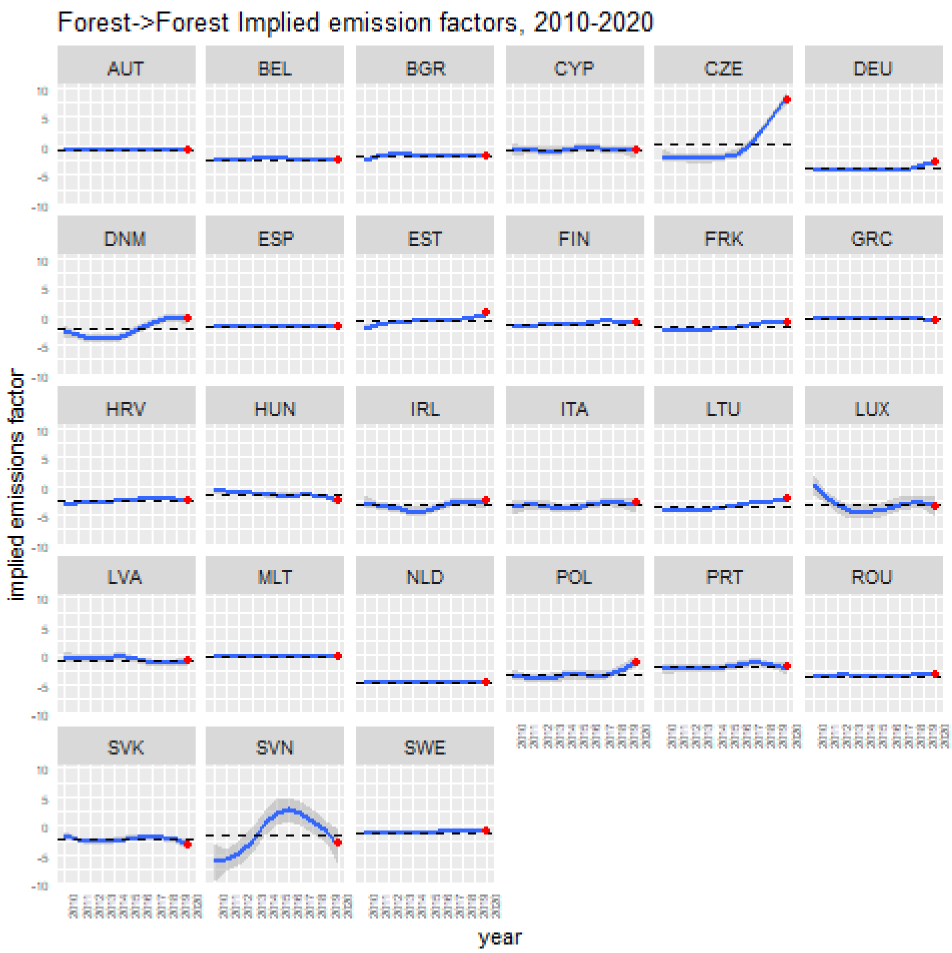
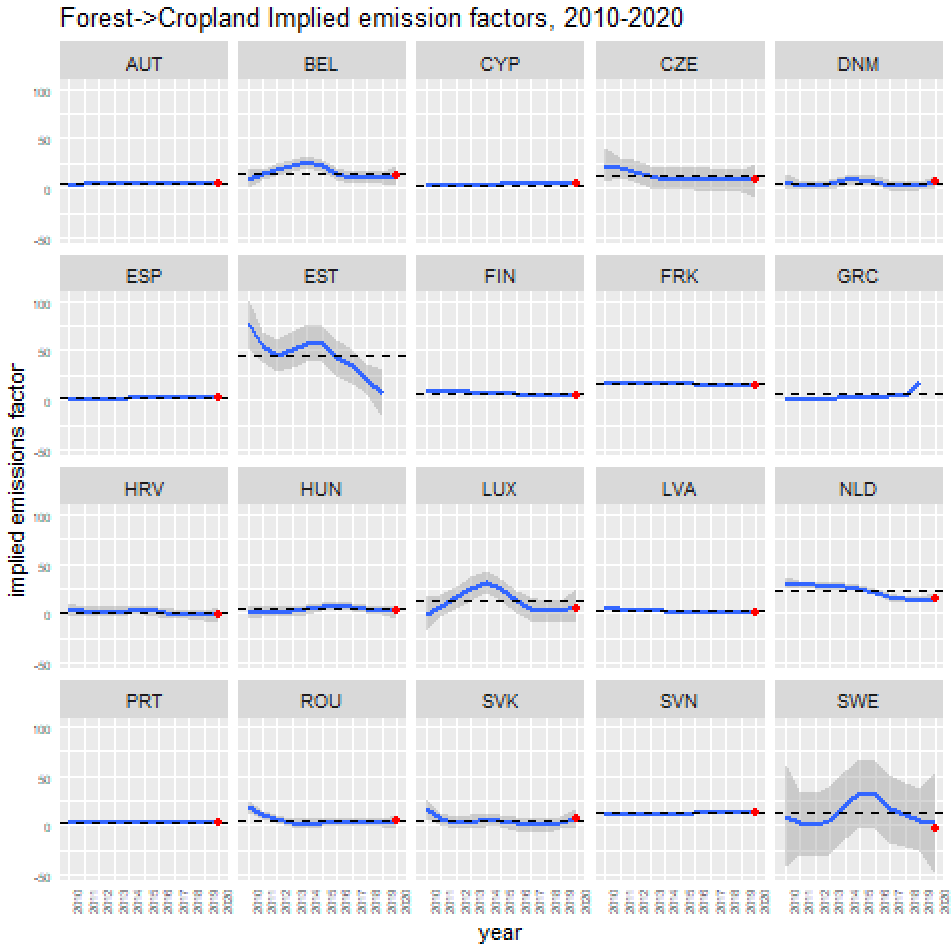
Annexes

Annex 1. Variability of IEFs

Country-specific implied emission factors are specific to land use conversions and fluctuate over time. The following figures show the IEF for the specific conversions, as declared by the Member States. In some cases, the sign changes, meaning the same conversion from one year to the next may be negative or positive in terms of emissions. Some countries are constant over time while others fluctuate a great deal depending on the land use conversions that took place in the previous 20-year period. The figures below show the smoothed trendline with variation over time represented by a grey shaded area. The red dots represent the IEF declared in 2020 while the black dotted line represents the average value between 2010-2020. This is the value that is used in the model to compute future emissions per land use conversion. Not all countries report IEF for all conversion types. Missing data is due to not observed, not estimated or unavailable data.





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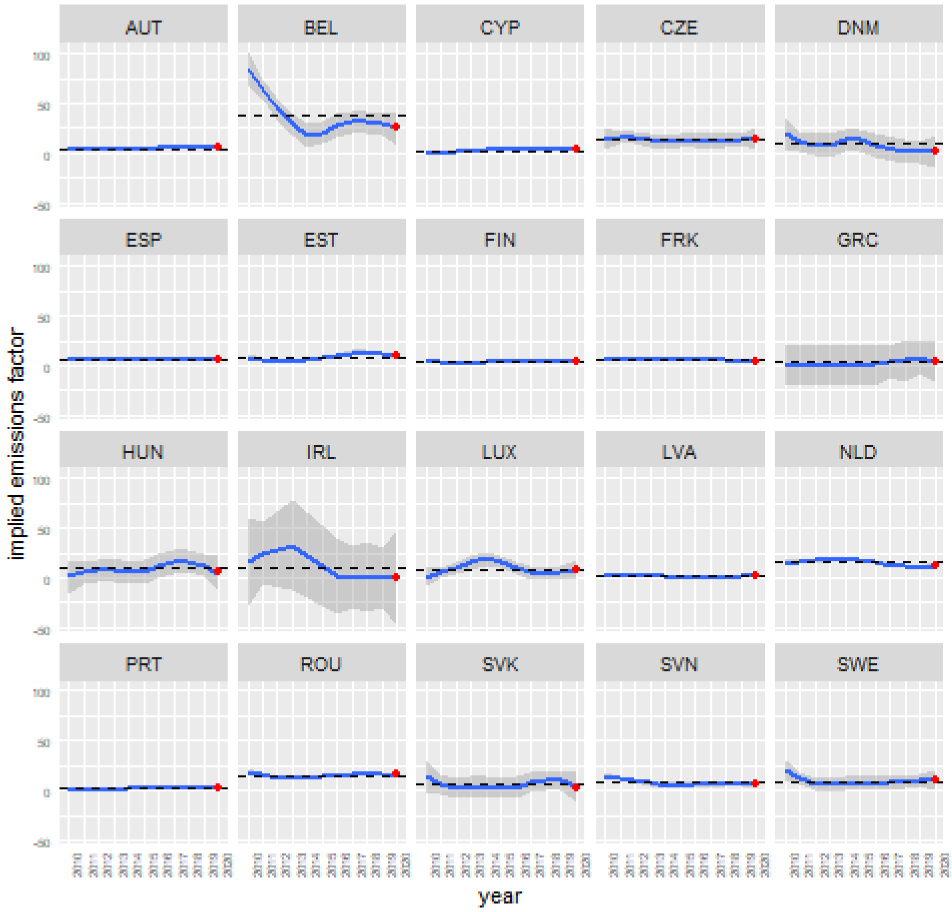
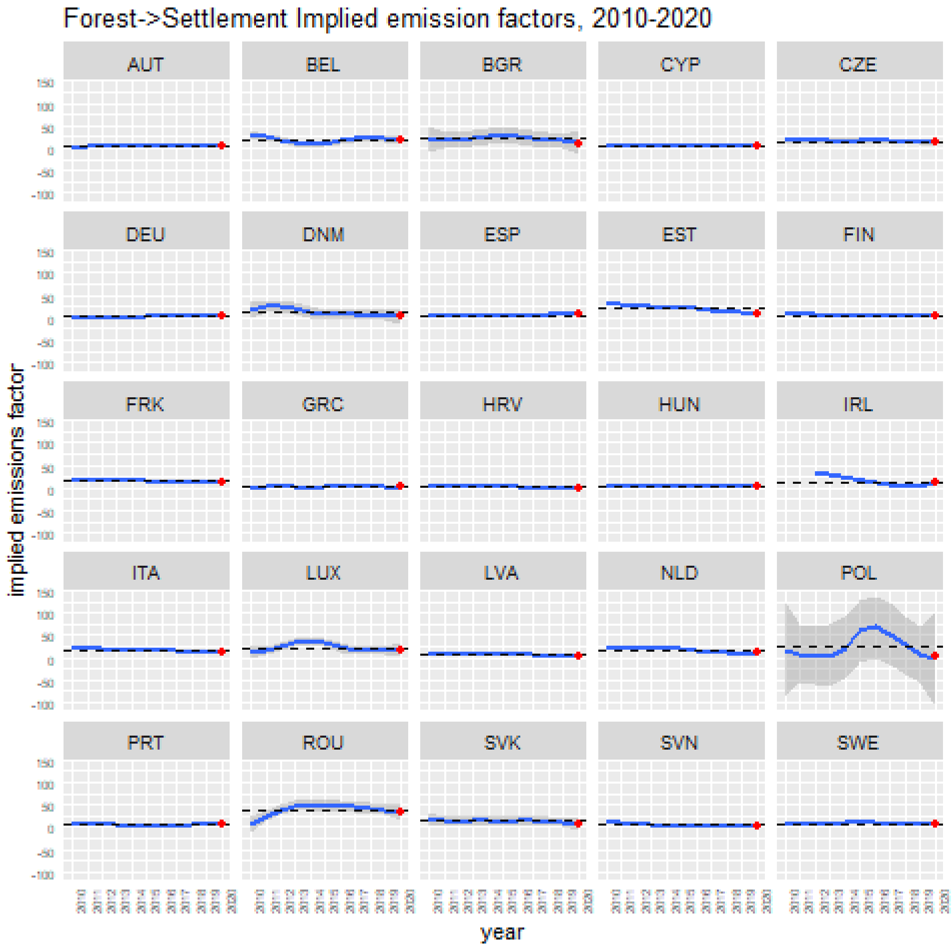
Forest->Grassland Implied emission factors, 2010-2020

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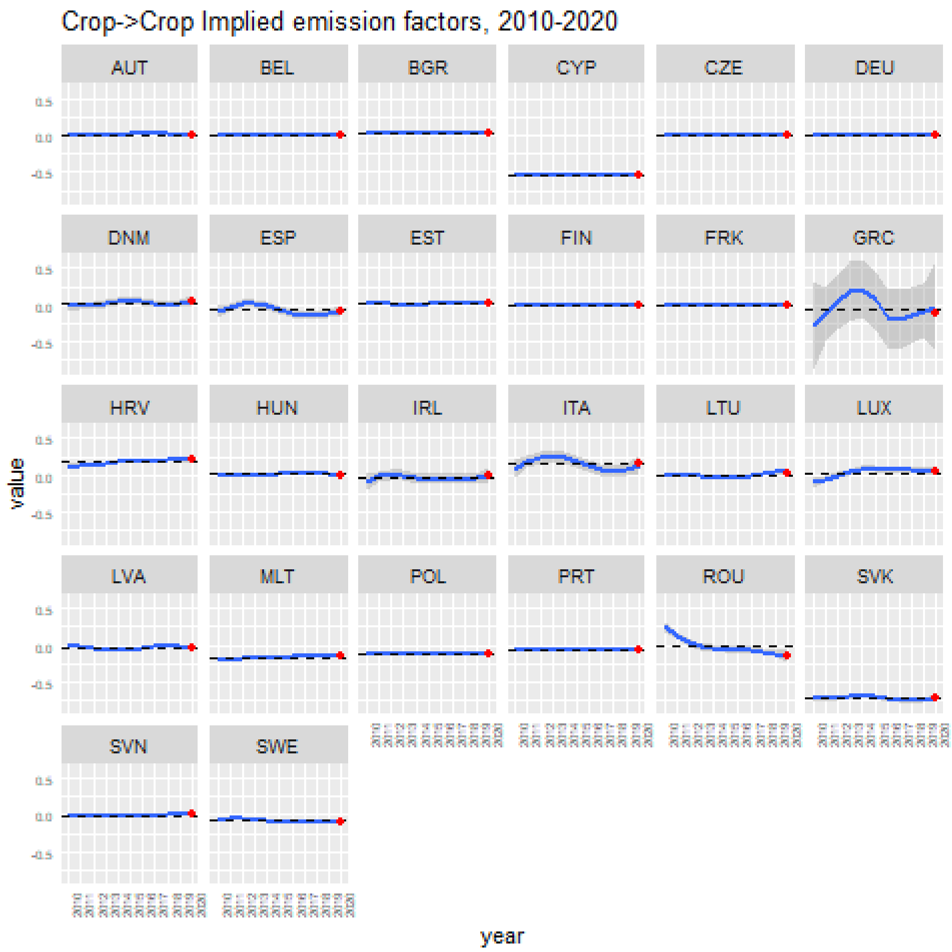
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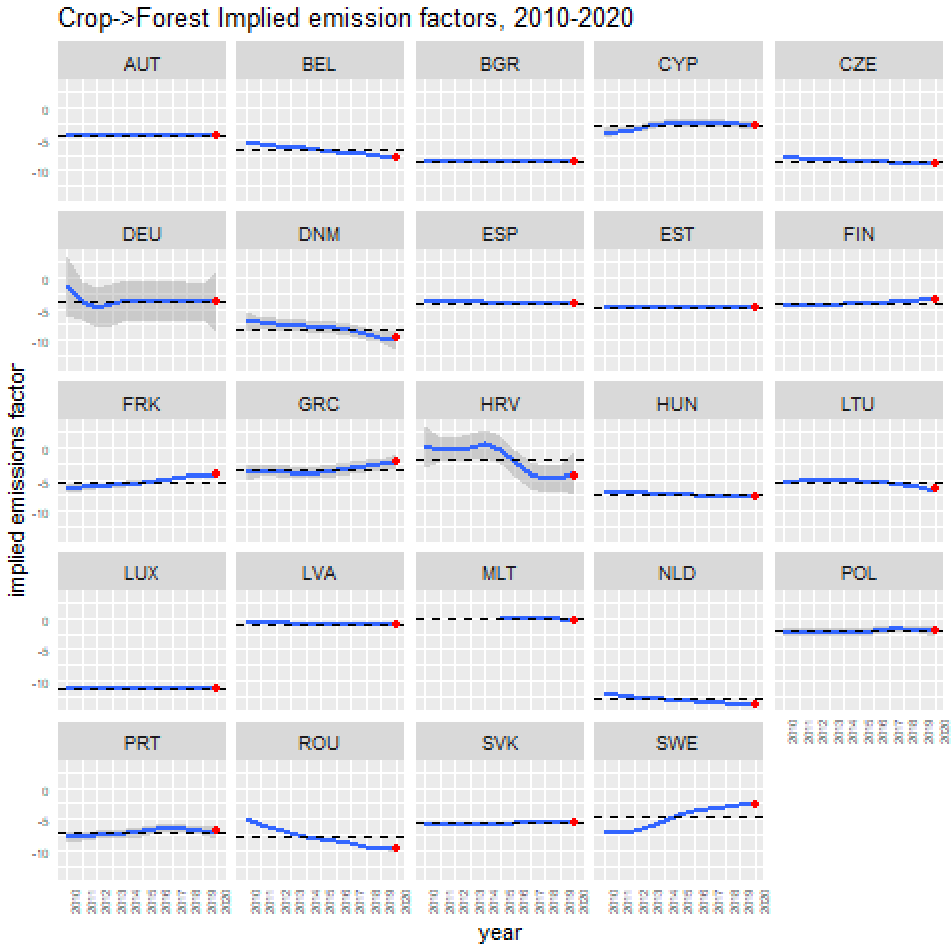

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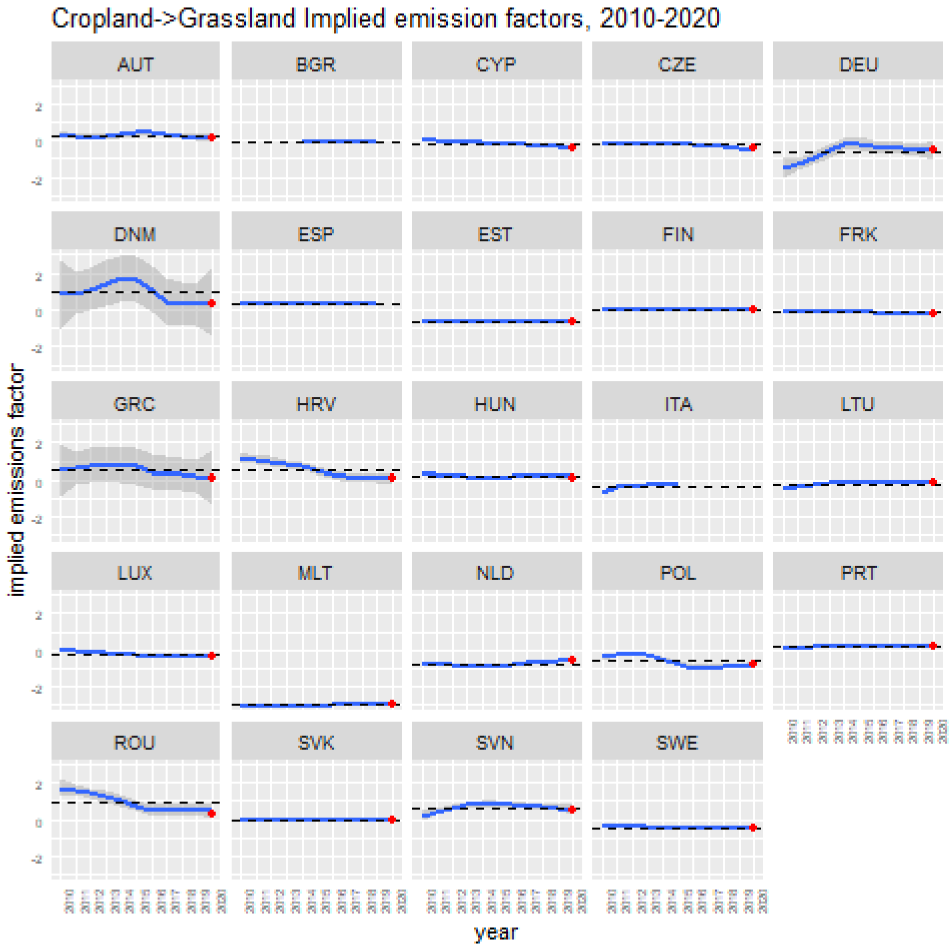
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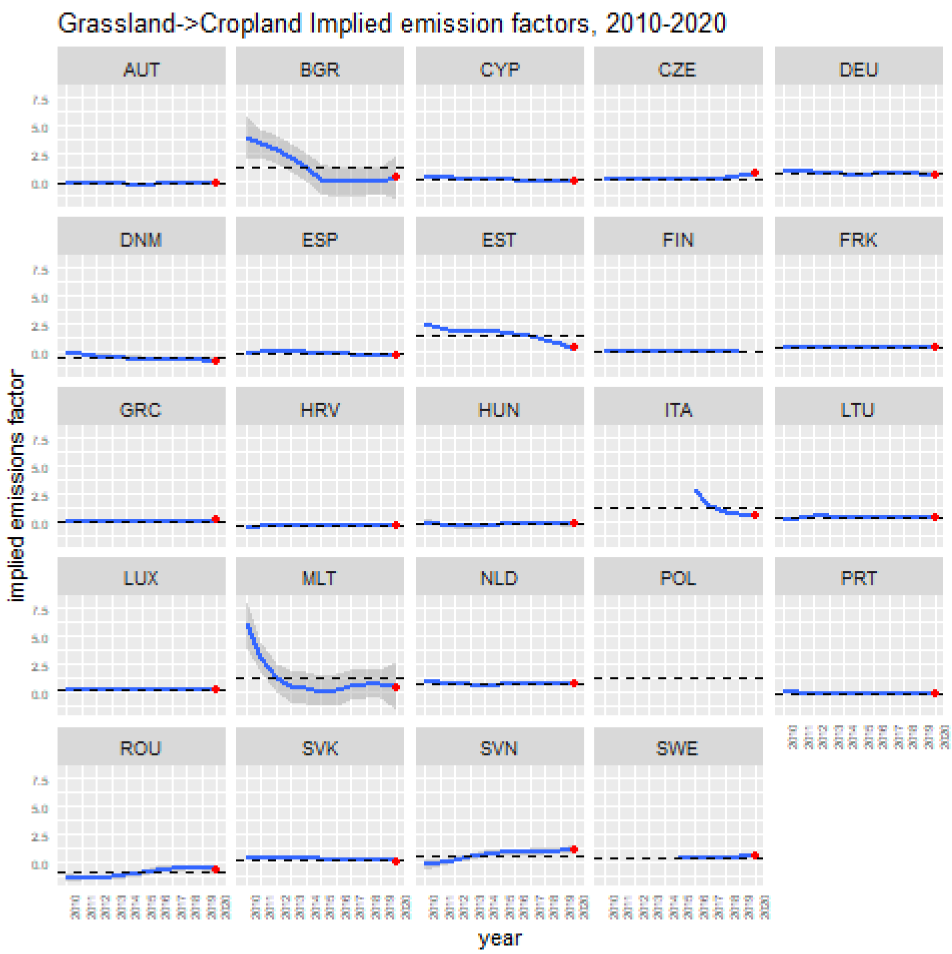
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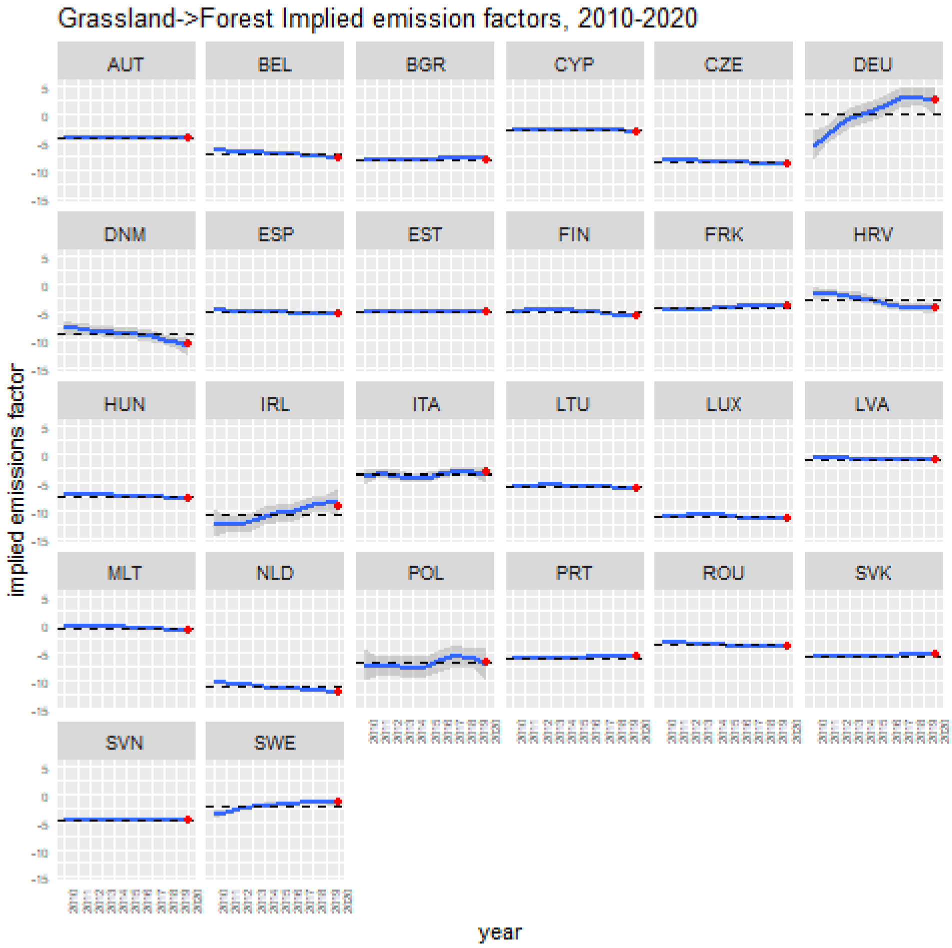

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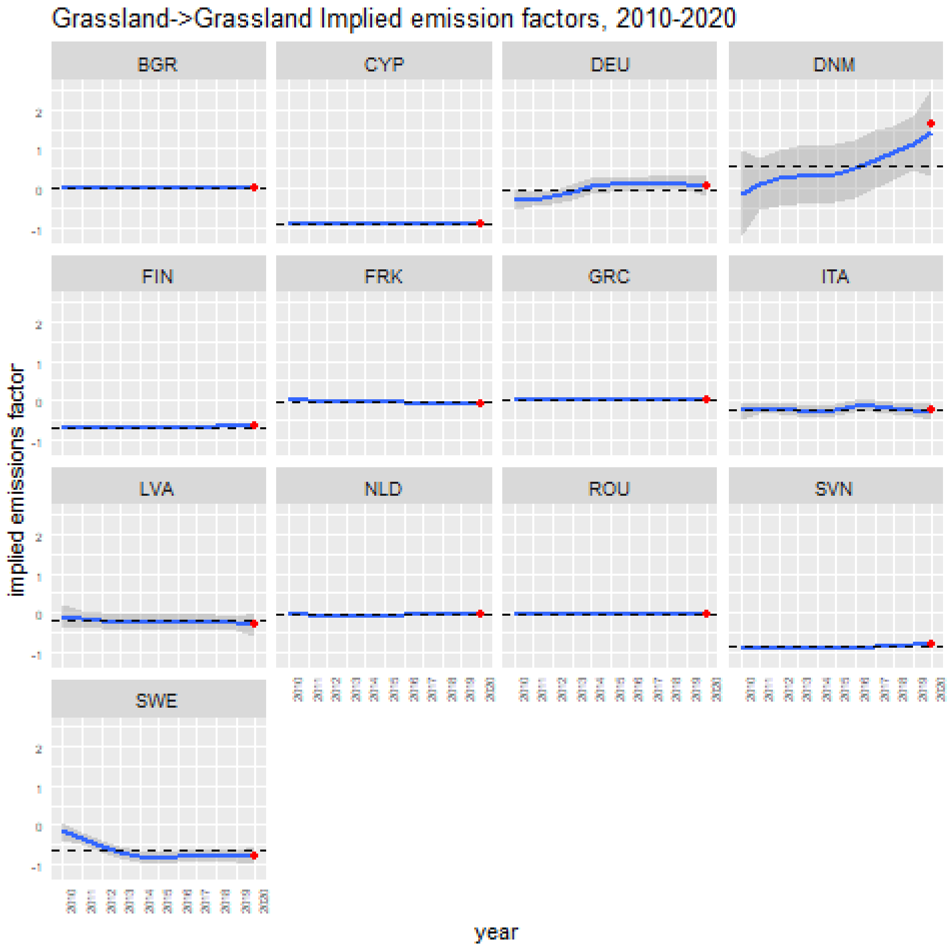
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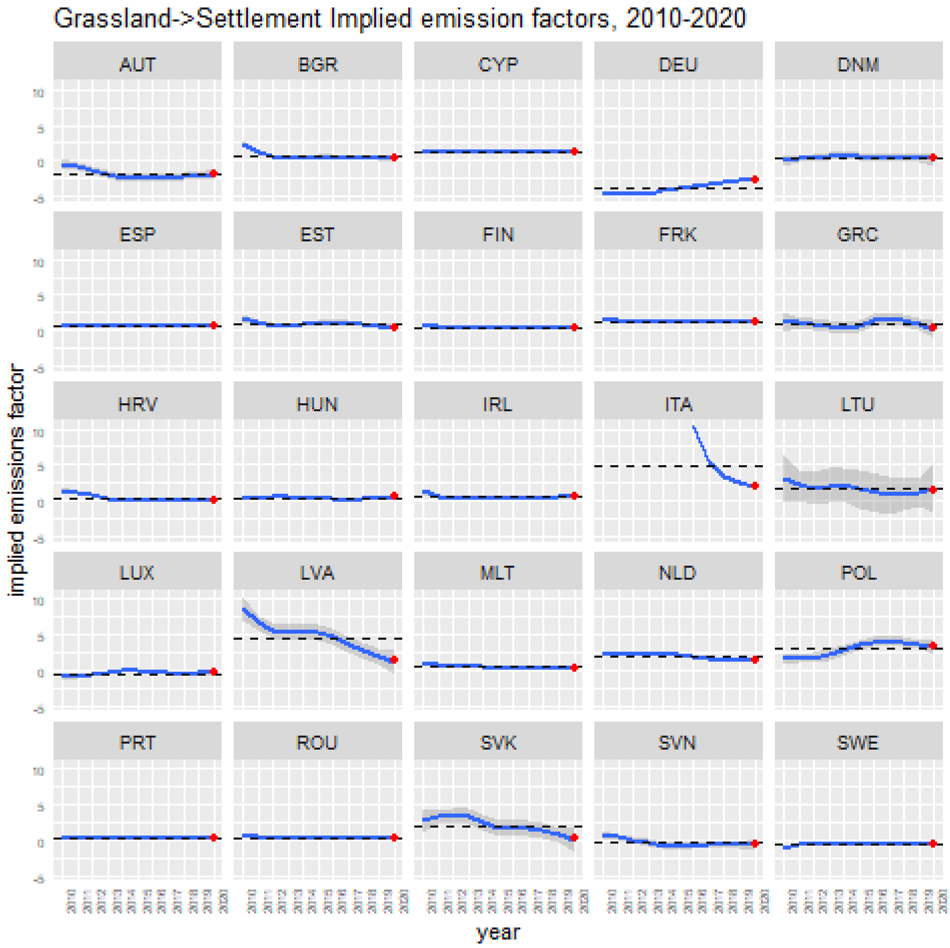
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Annex 2. LULUCF emissions comparison by source

Table 7 summarises the total LULUCF emissions in tonnes CO_2 equivalent/a, as computed by the model and as declared in the UNFCCC reporting.

Table 7. Comparison of model output and UNFCCC declarations, 2020.

Party	model	unfccc
Austria	-3,205,149	-1,266,557
Bulgaria	-7,551,581	-9,633,712
Croatia	-7,059,342	-5,317,778
Cyprus	-532,300	-348,753
Czech Republic	786,724	12,772,887
Denmark	259,362	3,130,464
Estonia	-2,281,254	1,272,129
Finland	-34,640,269	-17,435,181
France	-31,706,941	-14,188,425
Germany	-45,331,011	-11,207,699
Greece	-2,412,356	-3,952,512
Hungary	-3,345,762	-6,824,248
Ireland	-2,625,600	6,943,199
Italy	-33,562,598	-32,416,583
Latvia	-3,157,657	671,447
Lithuania	-7,913,993	-5,427,579
Malta	43	-2,192
Netherlands	-1,824,610	3,521,205
Poland	-32,781,344	-21,190,045
Portugal	-6,371,669	-6,813,406
Romania	-26,978,272	-32,896,261
Slovakia	-5,328,290	-8,748,382
Slovenia	-2,355,277	-4,739,633
Spain	-35,496,032	-35,558,488
Sweden	-36,949,459	-39,851,937
EU	-334,237,313	-229,856,861

Table 7 shows strong mismatches for the majority of countries. Although the reasons behind the discrepancies are always country-specific, five broad categories are described in section 6.2.

Annex 3. IPCC Tiered methods

Specifically, for the LULUCF sector the IPCC 2006 GL provide at the level of carbon pool and land use category three tier methods than can be summarized as follow:

Tier 1	*Tier 2*	*Tier 3*
Use default methodologies (e.g., equations) with default emissions factors, and or coefficients that are often provided at the level of climate zones, global ecological zones, and soil types. Or, in some cases it is assumed that there is no net change in the carbon stock in long term. I.e., the pool is in equilibrium.	Use default methodologies (e.g., equations), which are often the same used in Tier 1, but involving country-specific factors, frequently in combination with some default parameters. The quality of its estimates strongly depends on the temporal and spatial scales of the data collection systems and the representativeness of the factors.	Use country-specific methodologies that involve highly disaggregated information that allows for fine spatial scale for estimating GHGs. Usually relates with modelling methodologies or fine temporal and spatial resolutions. (e.g., high intensity sample systems)

Generally, moving to higher tiers improves the inventory's accuracy and reduces uncertainty, but the complexity and resources required for conducting inventories also increase. Tiers 2 and 3 are sometimes referred to as higher-tier methods, and are generally considered to be more accurate.

If necessary, a combination of tiers can be used, e.g. Tier 2 can be used for biomass and Tier 1 for soil carbon.

The methods and data presented could be approximated to a tier 1/2 method. Where carbon stock from dedicated studies are used along with the IPCC approaches. . inventories, but the default data presented for Tier 1 will be partly or wholly replaced with national data as part of the Tier 2 estimation. Tier 3 methods are not described in detail, but good practices in their application are outlined. The framework of the Tier structure for AFOLU methods is as follows:

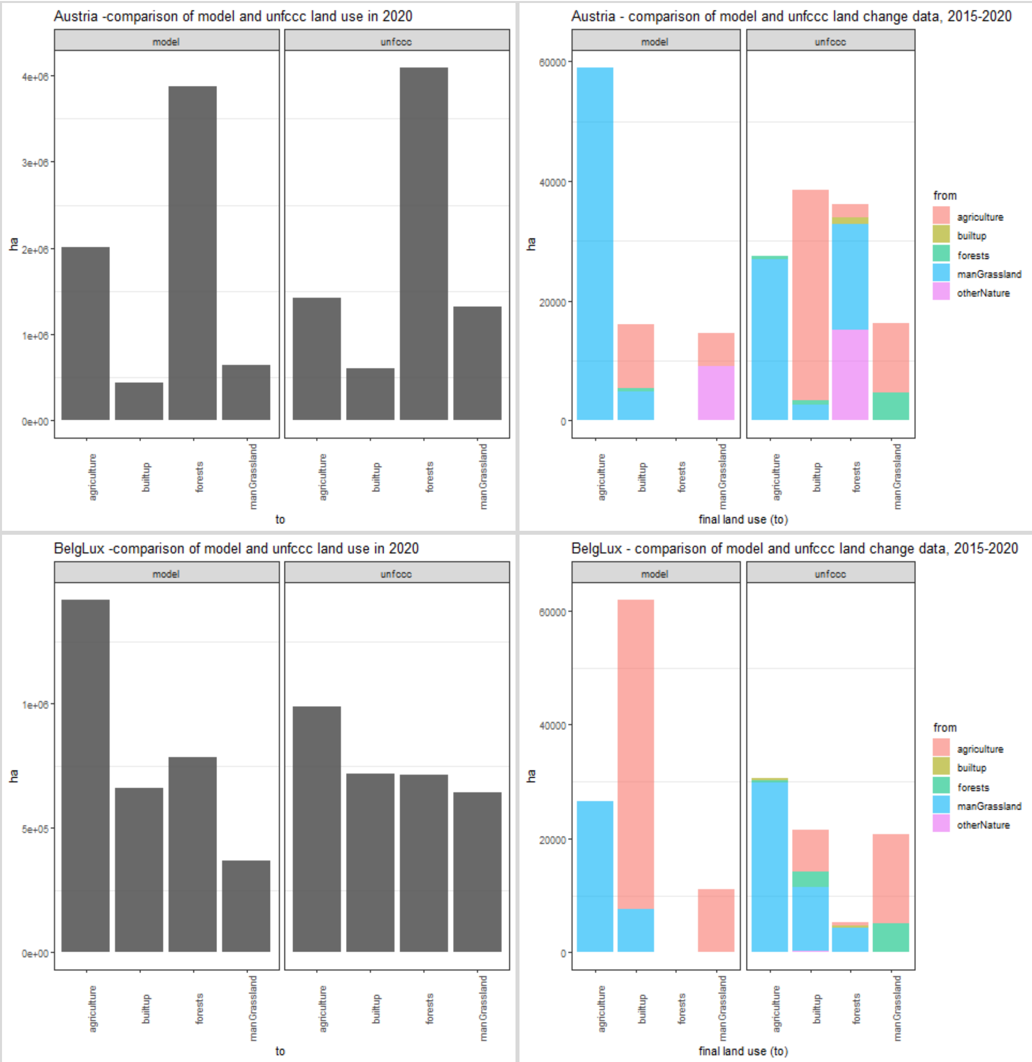
- Tier 1 methods are designed to be the simplest to use; equations and default parameter values (e.g., emission and stock change factors) for these methods are provided by IPCC guidelines. Country-specific activity data are necessary, but for Tier 1 sources of activity data estimates are often globally available (e.g. deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.), although these data are usually spatially coarse. It is good practice to use data from official international sources when national data are lacking.

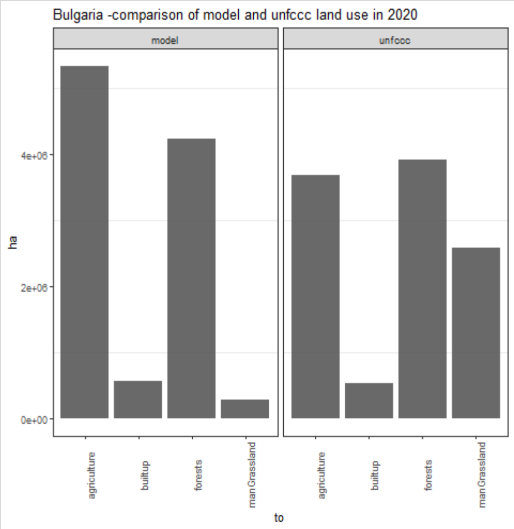
- Tier 2 can use the same methodological approach as Tier 1, but applies emission and stock change factothat are based on country- or region-specific data, for the most important land-use or livestock categories.Country-defined emission factors are more appropriate for the climatic regions, land-use systems and livestock categories in that country. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

- In Tier 3, higher order methods are used, including models and inventory measurement systems tailored to national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at the sub-national level.

Annex 4. National-level comparisons of land use allocation between UNFCCC reporting and the land use model

The following series of graphs presents the overall land allocation (in hectares) of the four main land categories whose emissions are assessed in the model, as described in Figure 5, in the left column. In the right column, only the land use chages from->to are shown. Thus the total land area is smaller because we do not show the persistent land uses in these graphs. The amount of land that remains the same over a five-year period dominates and hides the expressiveness of the land use changes.

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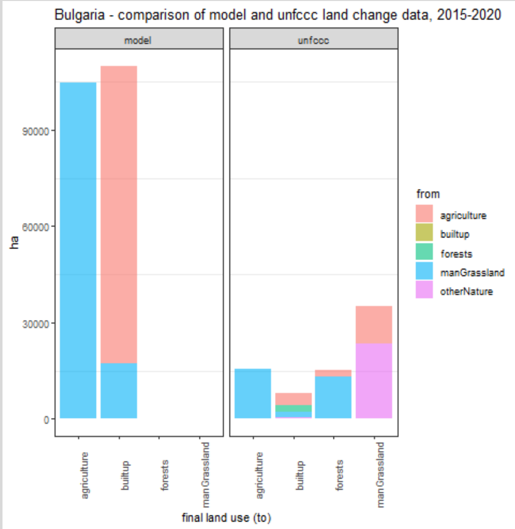
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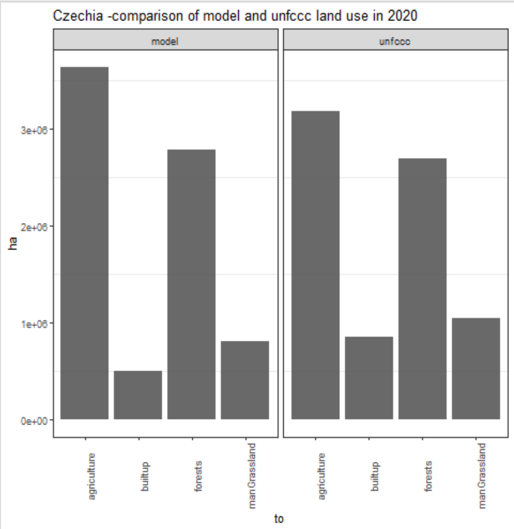
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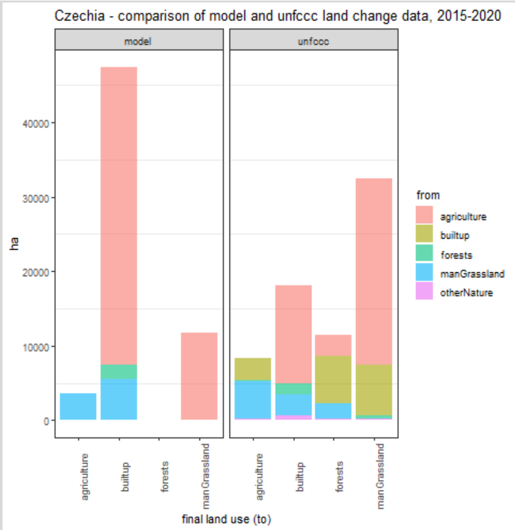
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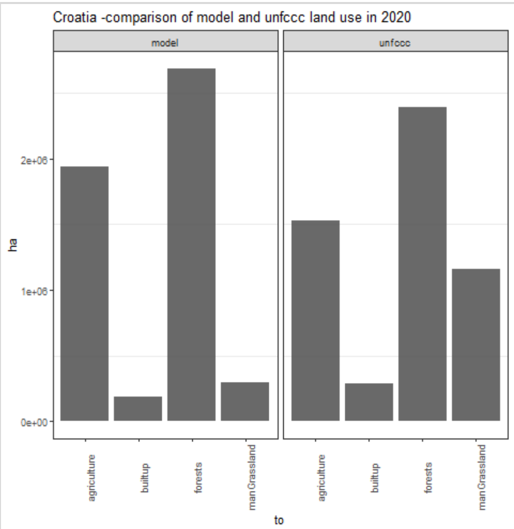
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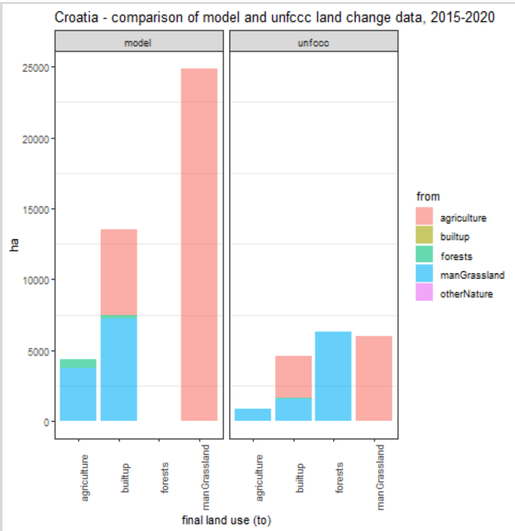
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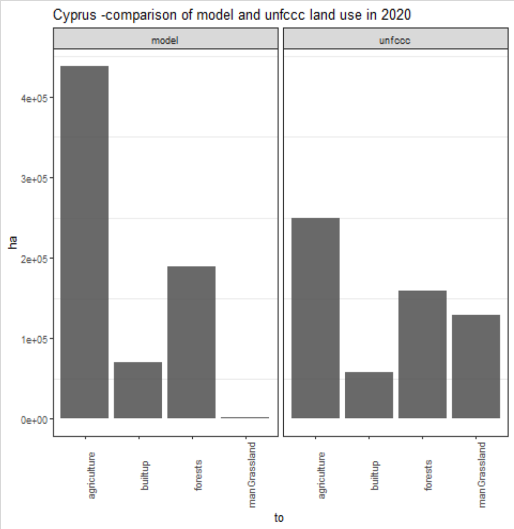
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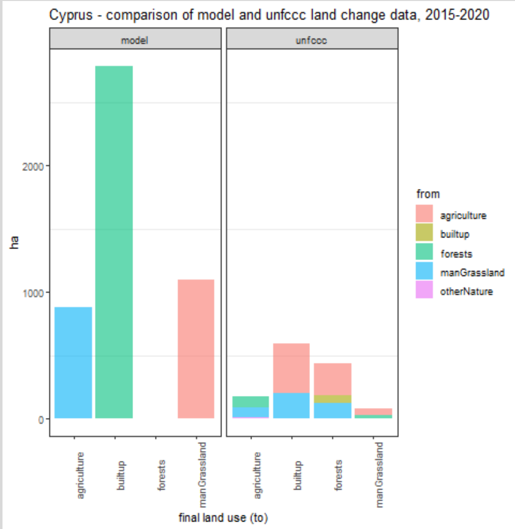
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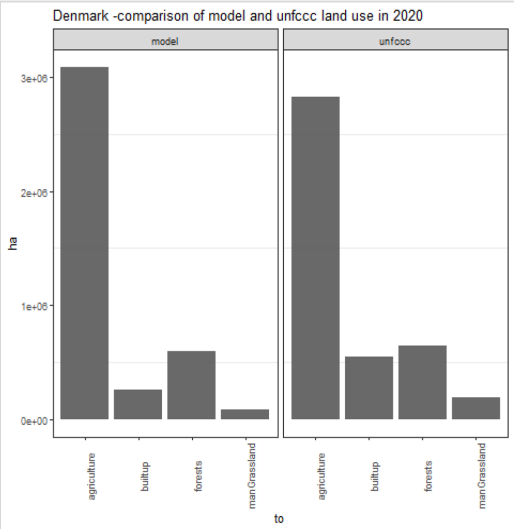
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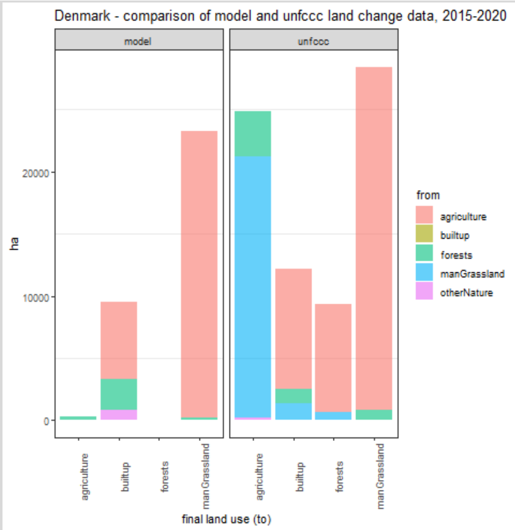
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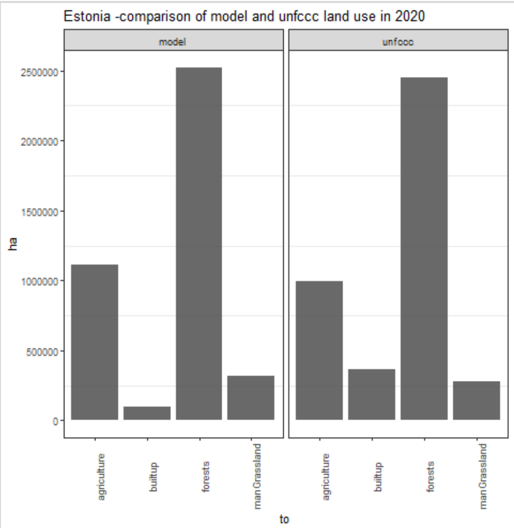
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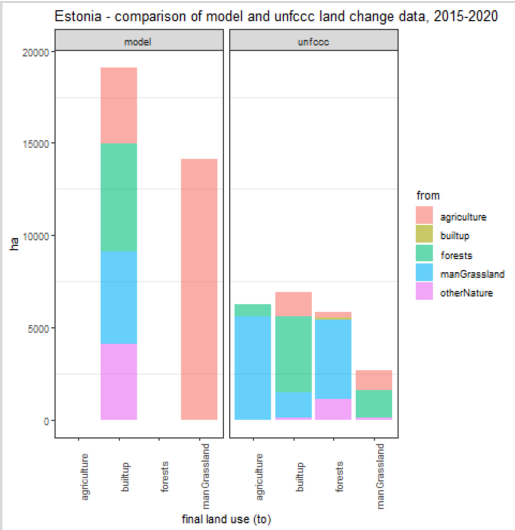
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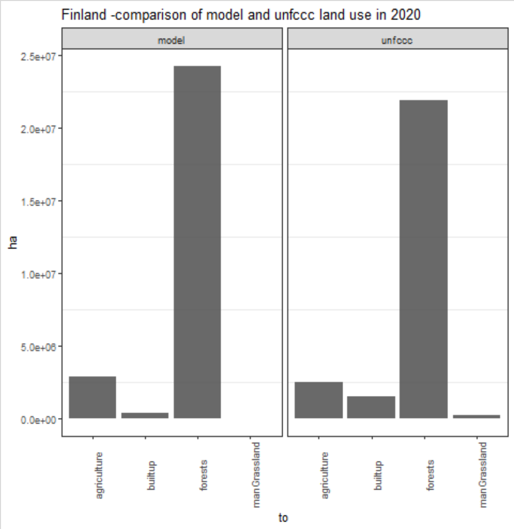
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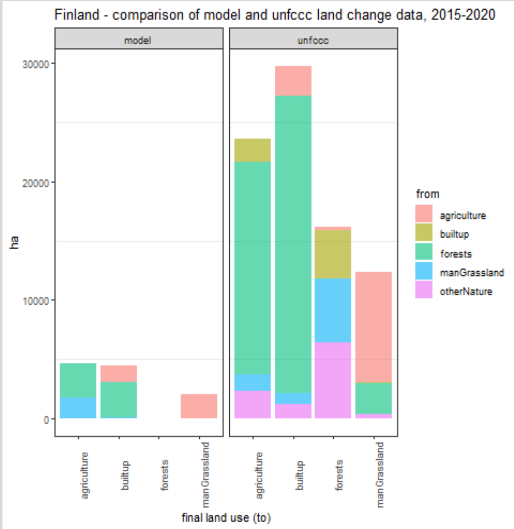
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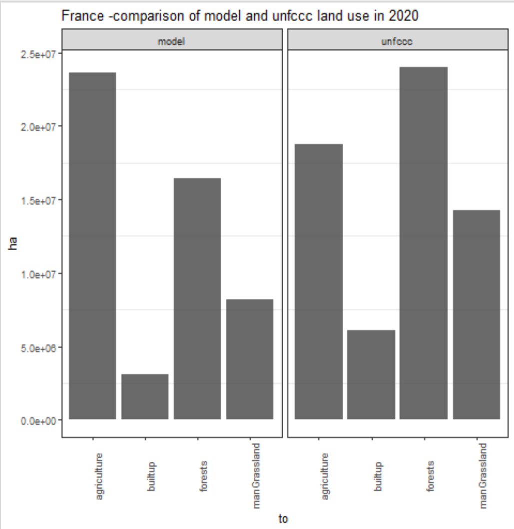
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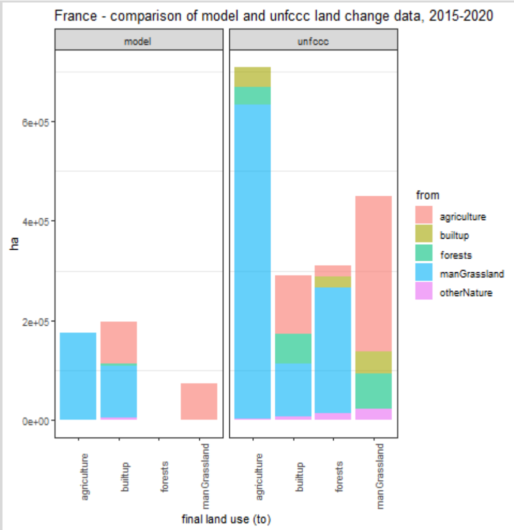
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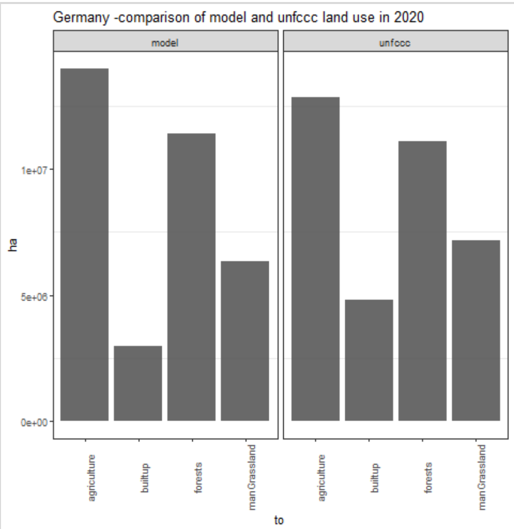
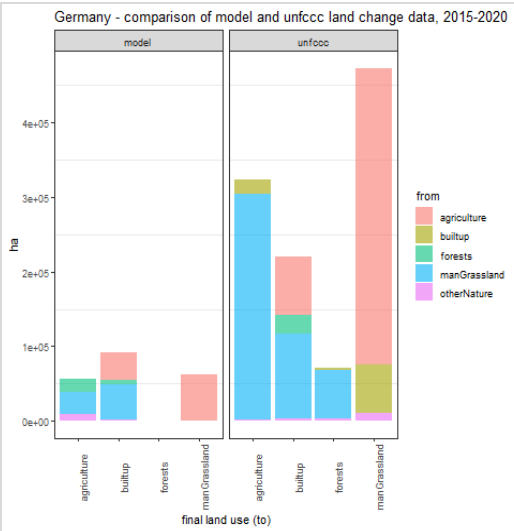
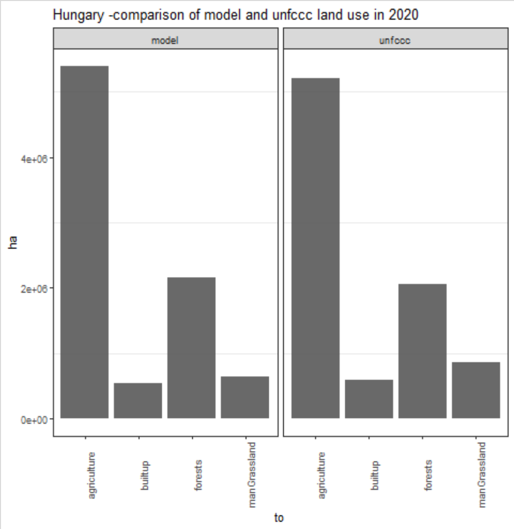
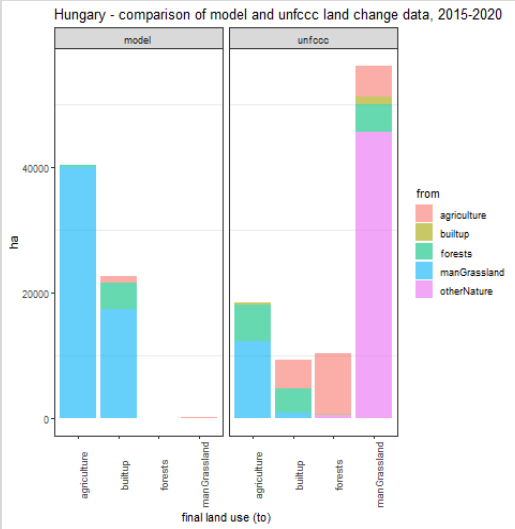
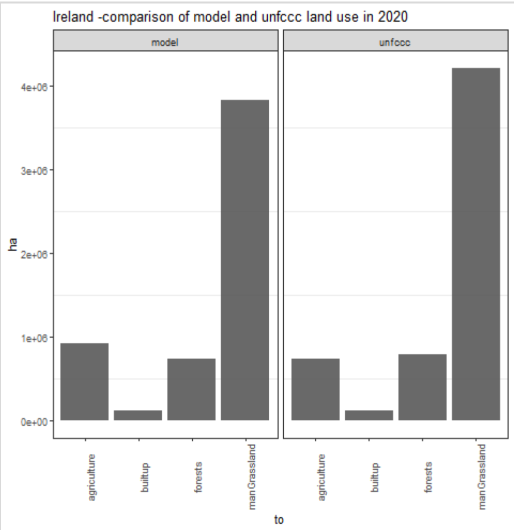
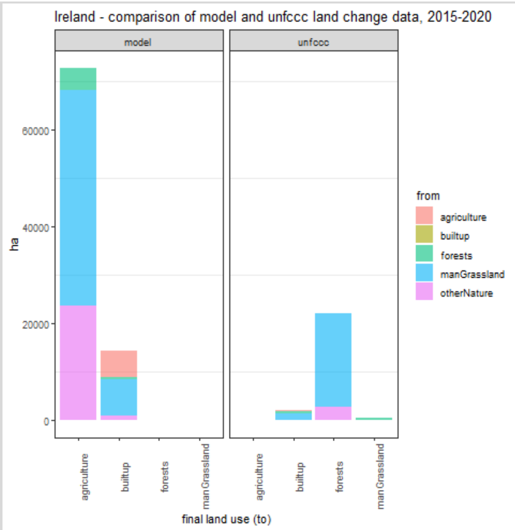

Germany -comparison of model and unfccc land use in 2020
model
unfccc
ha
1e+07
5e+06
0e+00
agriculture
builtup
forests
manGrassland
to

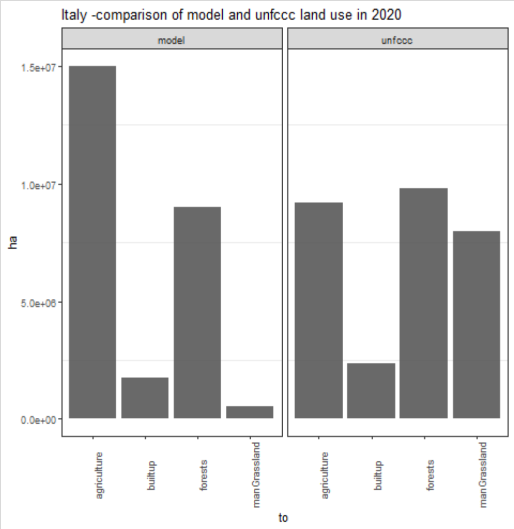

Germany - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
4e+05
3e+05
2e+05
1e+05
0e+00
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

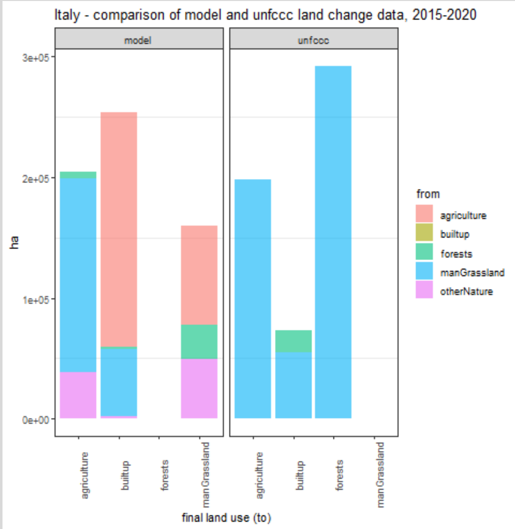

Hungary -comparison of model and unfccc land use in 2020
model
unfccc
ha
4e+06
2e+06
0e+00
agriculture
builtup
forests
manGrassland
to

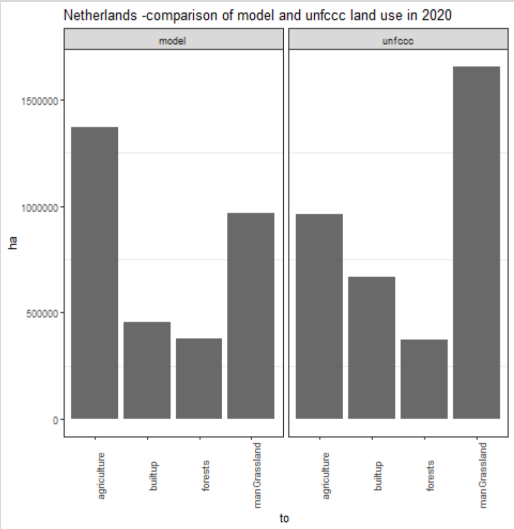

Hungary - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
40000
20000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

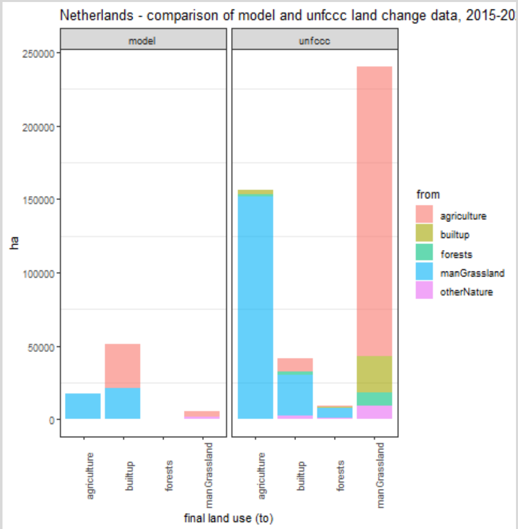

Ireland -comparison of model and unfccc land use in 2020
model
unfccc
ha
4e+06
3e+06
2e+06
1e+06
0e+00
agriculture
builtup
forests
manGrassland
to

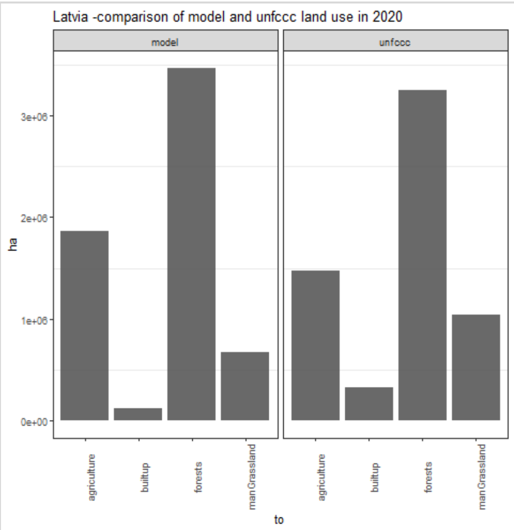

Ireland - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
60000
40000
20000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

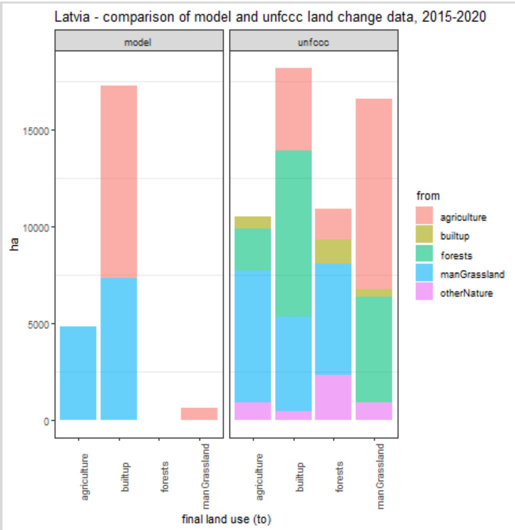

Italy -comparison of model and unfccc land use in 2020
model
unfccc
ha
1.5e+07
1.0e+07
5.0e+06
0.0e+00
agriculture
builtup
forests
manGrassland
to

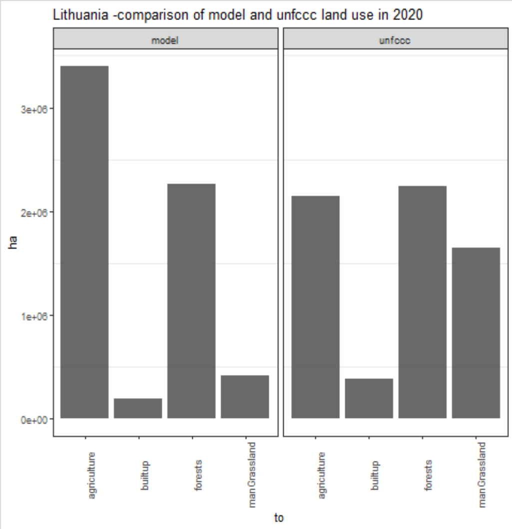

Italy - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
3e+05
2e+05
1e+05
0e+00
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

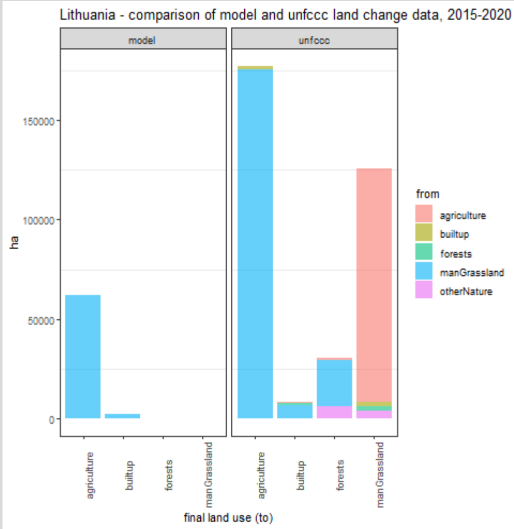

Netherlands -comparison of model and unfccc land use in 2020
model
unfccc
ha
1500000
1000000
500000
0
agriculture
builtup
forests
manGrassland
to

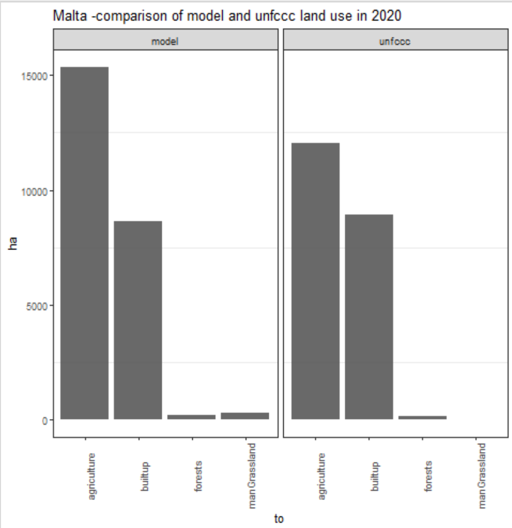

Netherlands - comparison of model and unfccc land change data, 2015-20
model
unfccc
ha
250000
200000
150000
100000
50000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

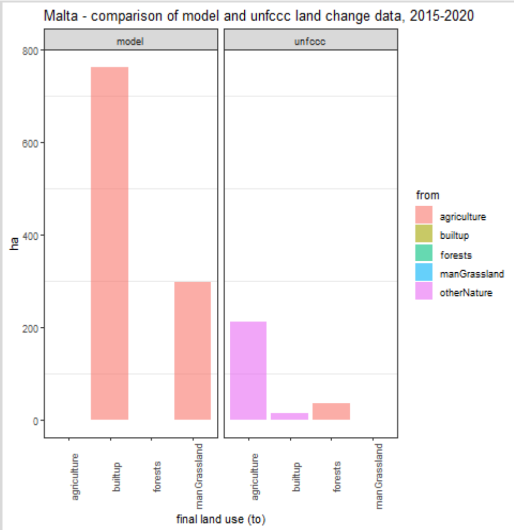

Latvia -comparison of model and unfccc land use in 2020
model
unfccc
ha
3e+06
2e+06
1e+06
0e+00
agriculture
builtup
forests
manGrassland
to

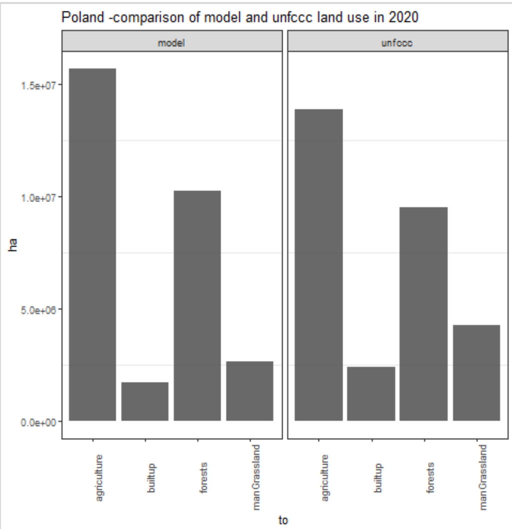

Latvia - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
15000
10000
5000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

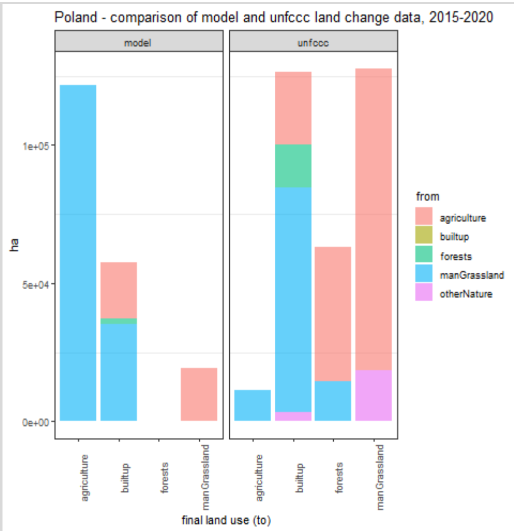

Lithuania -comparison of model and unfccc land use in 2020
model
unfccc
ha
3e+06
2e+06
1e+06
0e+00
agriculture
builtup
forests
manGrassland
to

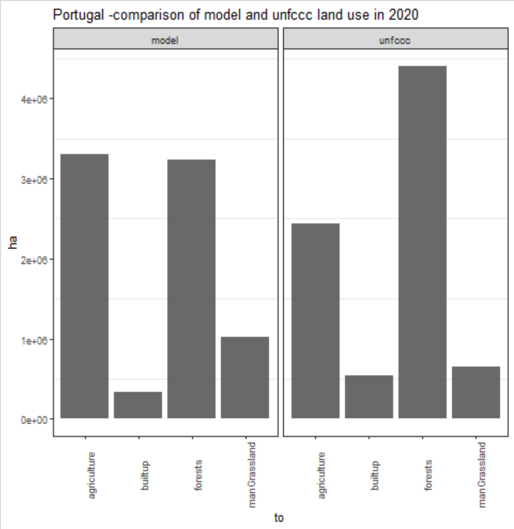

Lithuania - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
150000
100000
50000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

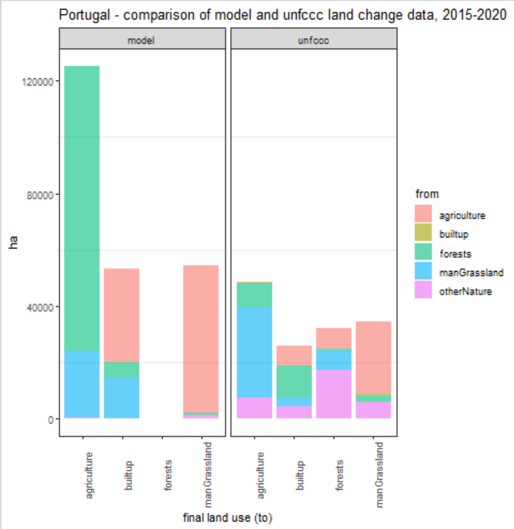

Malta -comparison of model and unfccc land use in 2020
model
unfccc
ha
15000
10000
5000
0
agriculture
builtup
forests
manGrassland
to

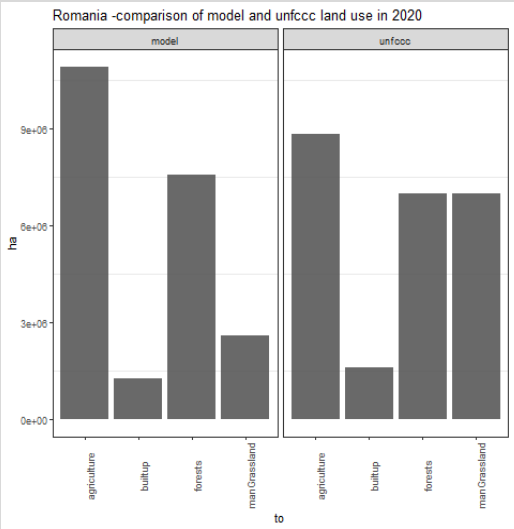

Malta - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
800
600
400
200
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

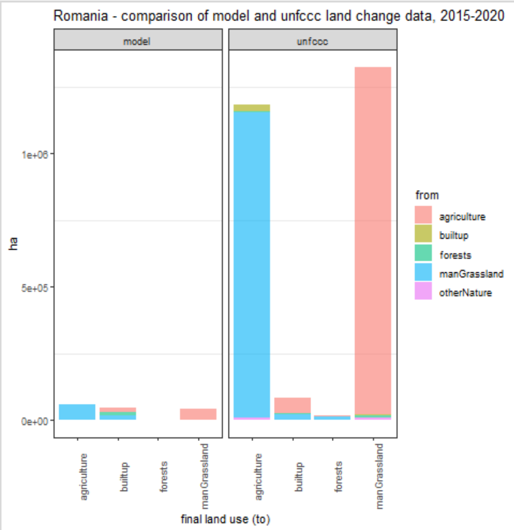

Poland -comparison of model and unfccc land use in 2020
model
unfccc
ha
1.5e+07
1.0e+07
5.0e+06
0.0e+00
agriculture
builtup
forests
manGrassland
to

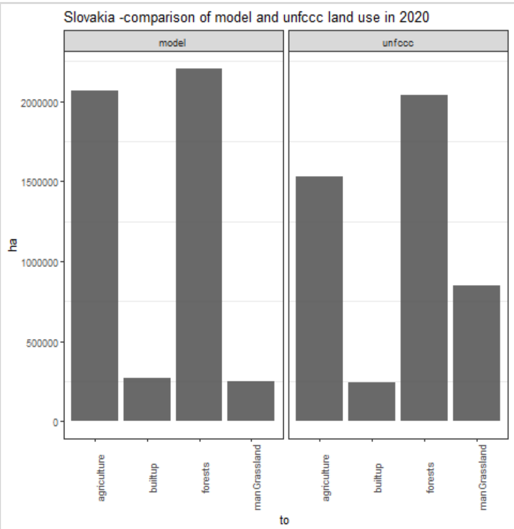

Poland - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
1e+05
5e+04
0e+00
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

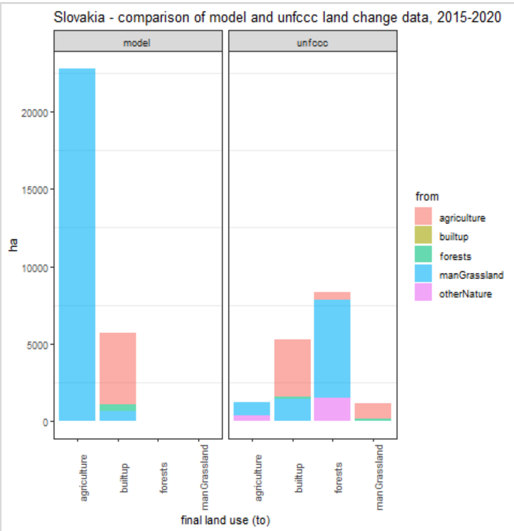

Portugal -comparison of model and unfccc land use in 2020
model
unfccc
ha
4e+06
3e+06
2e+06
1e+06
0e+00
agriculture
builtup
forests
manGrassland
to

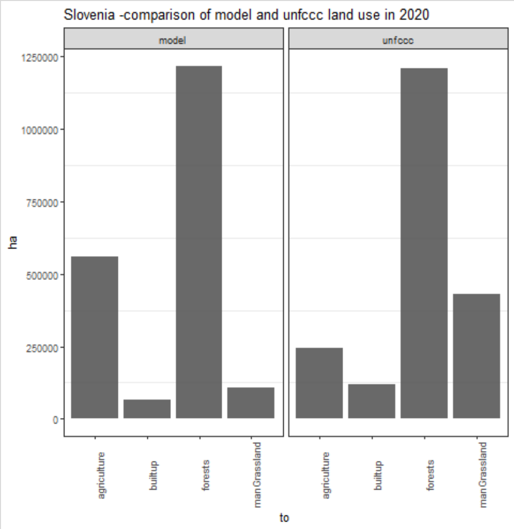

Portugal - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
120000
80000
40000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

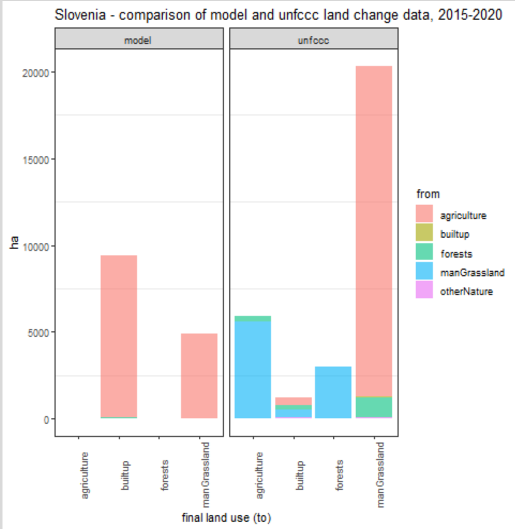

Romania -comparison of model and unfccc land use in 2020
model
unfccc
ha
9e+06
6e+06
3e+06
0e+00
agriculture
builtup
forests
manGrassland
to

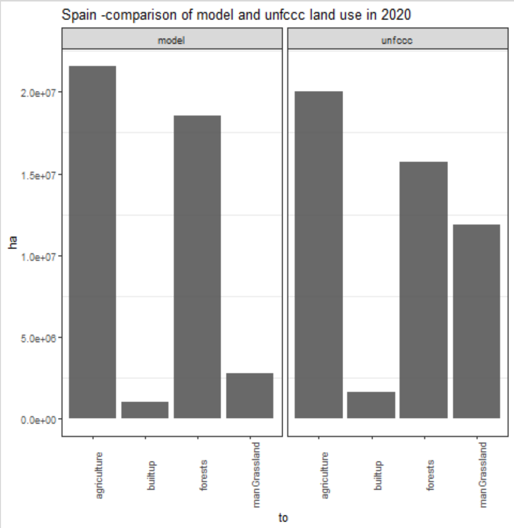

Romania - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
1e+06
5e+05
0e+00
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

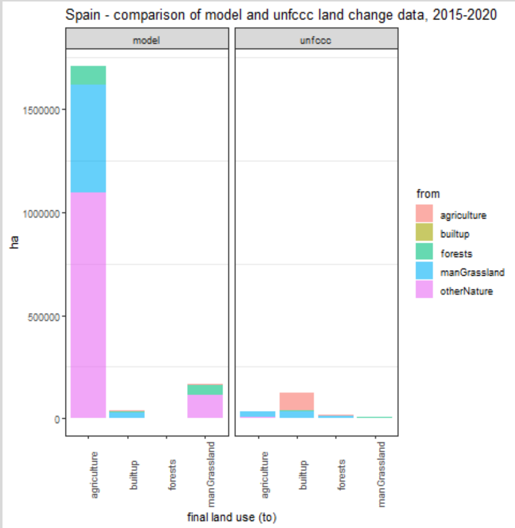

Slovakia -comparison of model and unfccc land use in 2020
model
unfccc
ha
2000000
1500000
1000000
500000
0
agriculture
builtup
forests
manGrassland
to

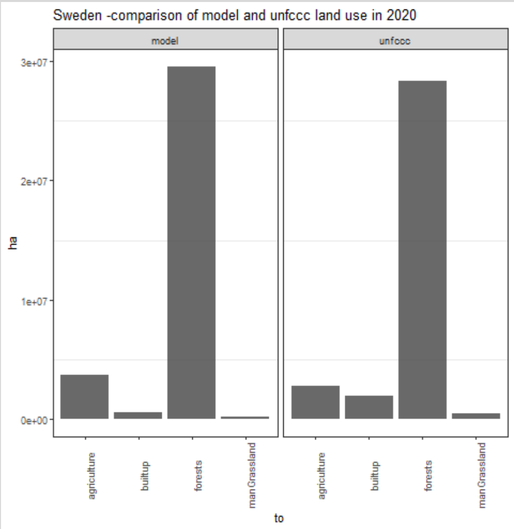

Slovakia - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
20000
15000
10000
5000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

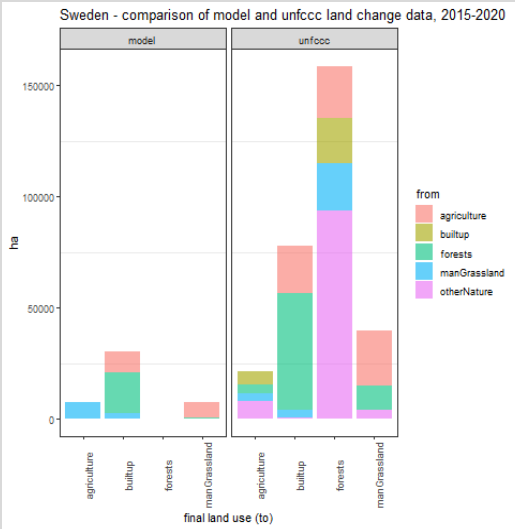

Slovenia -comparison of model and unfccc land use in 2020
model
unfccc
ha
1250000
1000000
750000
500000
250000
0
agriculture
builtup
forests
manGrassland
to


Slovenia - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
20000
15000
10000
5000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature


Spain -comparison of model and unfccc land use in 2020
model
unfccc
ha
2.0e+07
1.5e+07
1.0e+07
5.0e+06
0.0e+00
agriculture
builtup
forests
manGrassland
to

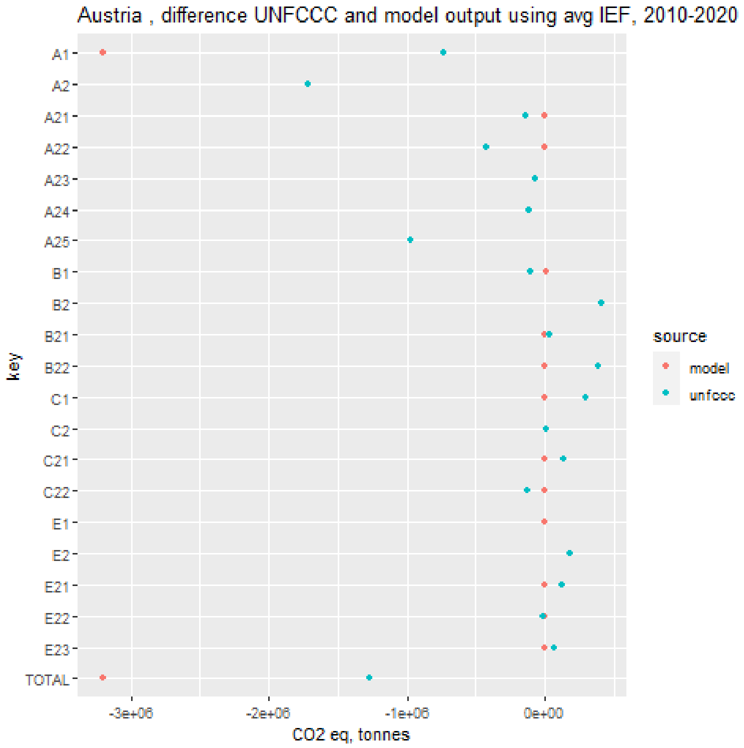

Spain - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
1500000
1000000
500000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

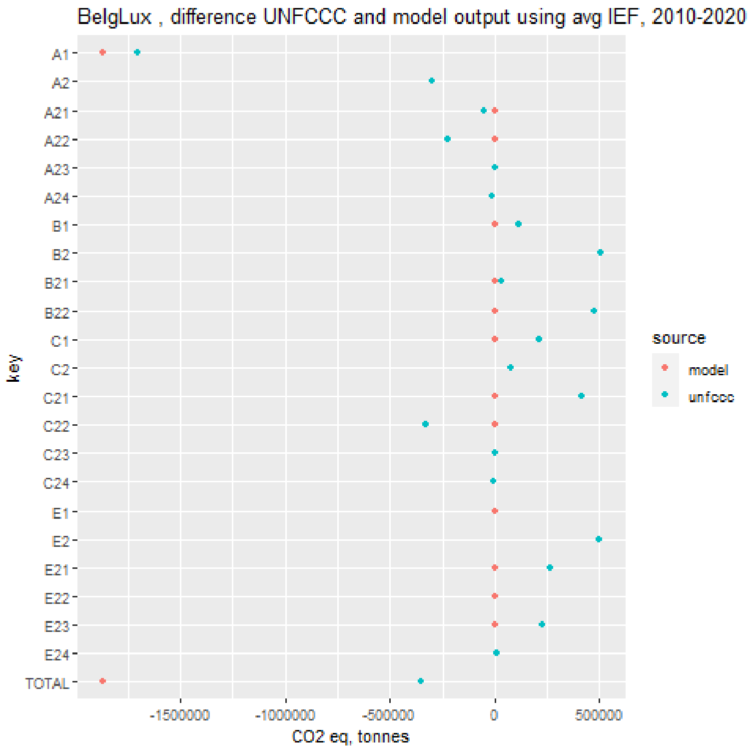

Sweden -comparison of model and unfccc land use in 2020
model
unfccc
ha
3e+07
2e+07
1e+07
0e+00
agriculture
builtup
forests
manGrassland
to

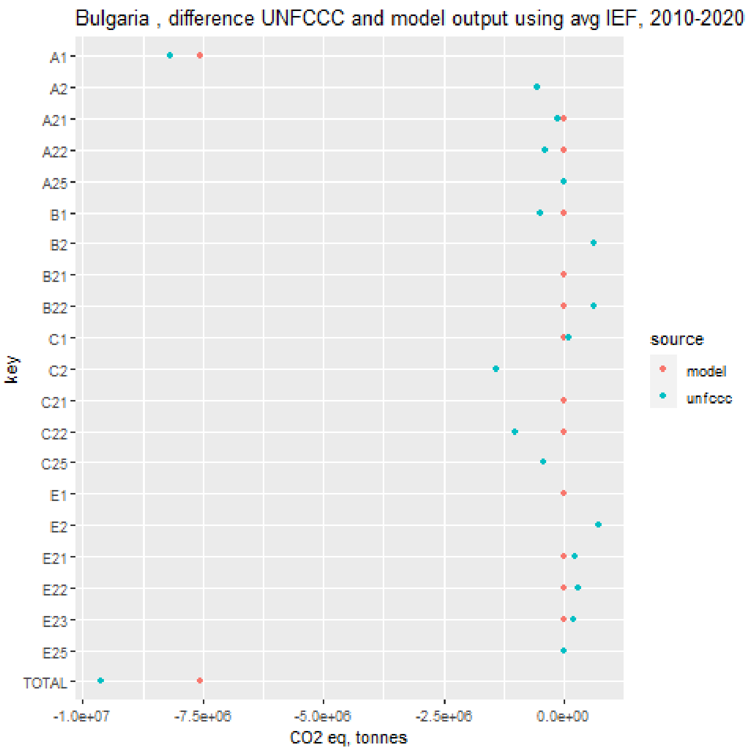

Sweden - comparison of model and unfccc land change data, 2015-2020
model
unfccc
ha
150000
100000
50000
0
agriculture
builtup
forests
manGrassland
final land use (to)
from
agriculture
builtup
forests
manGrassland
otherNature

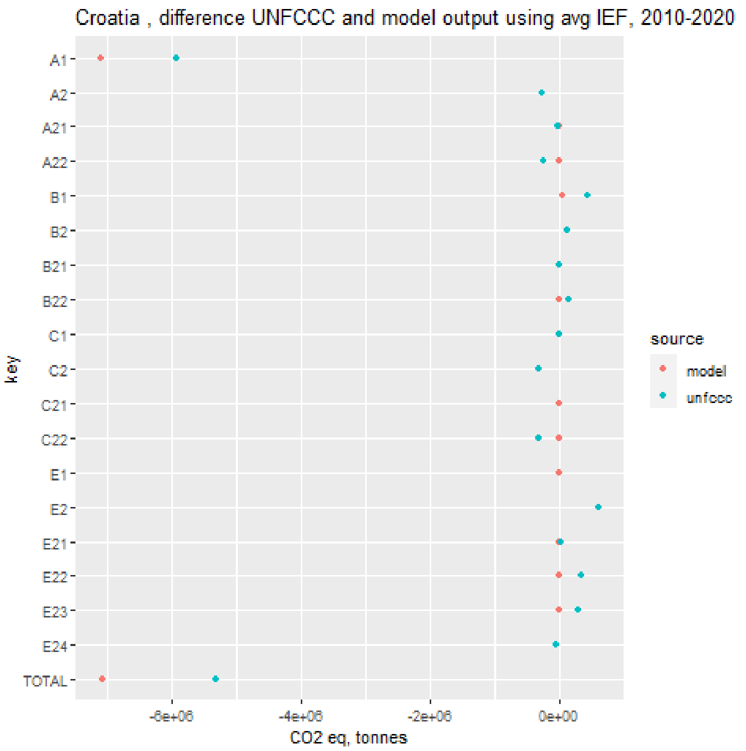
Annex 5. Comparison of emissions between countries by land use conversion pair

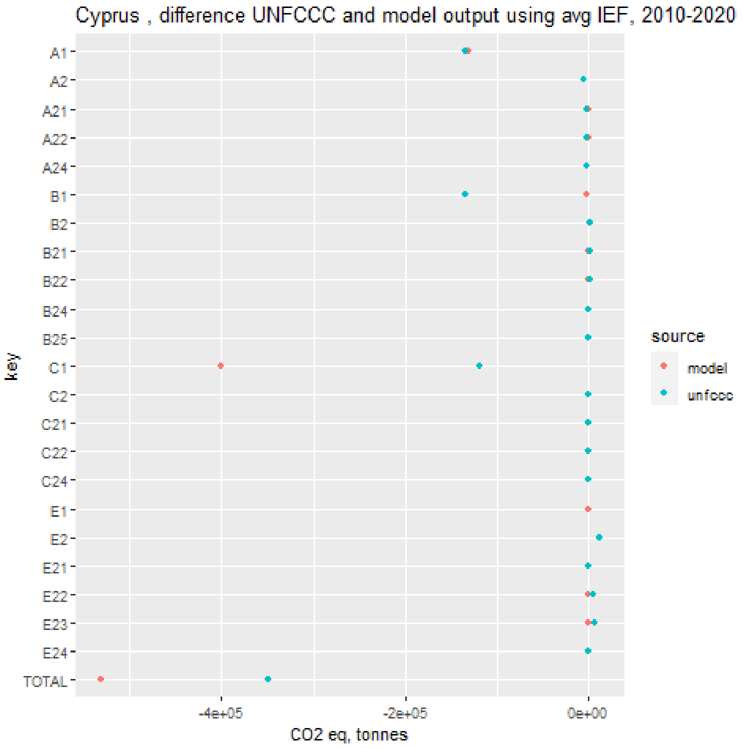
The differences in the total emissions per country for the individual land use conversion categories, as described in Figure 7, are shown in this annex. The total emissions for the whole sector is in the bottom row. The differences between reporting and model results are not consistent across countries, suggesting the need for a country-specific focus to resolve individual circumstances, as discussed in Section 6.3.

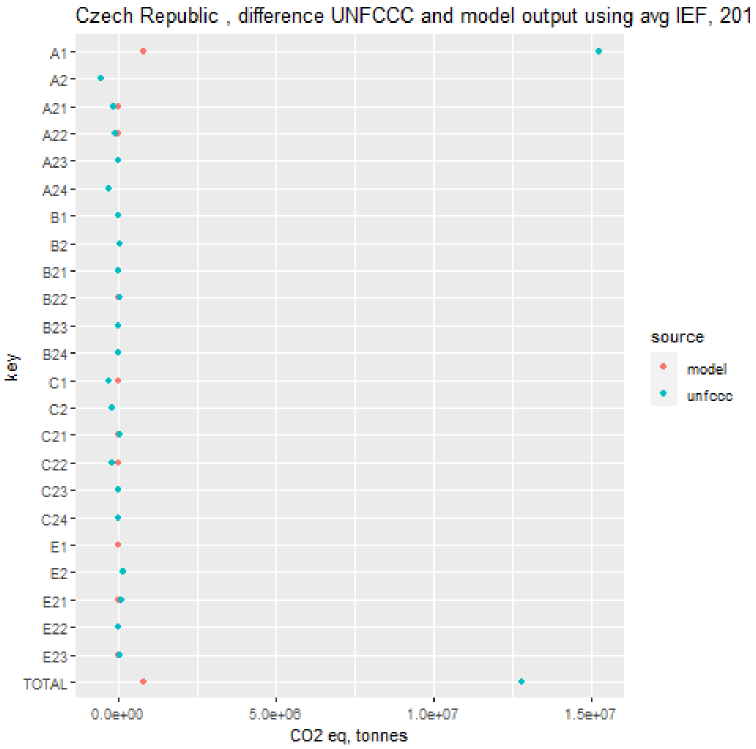


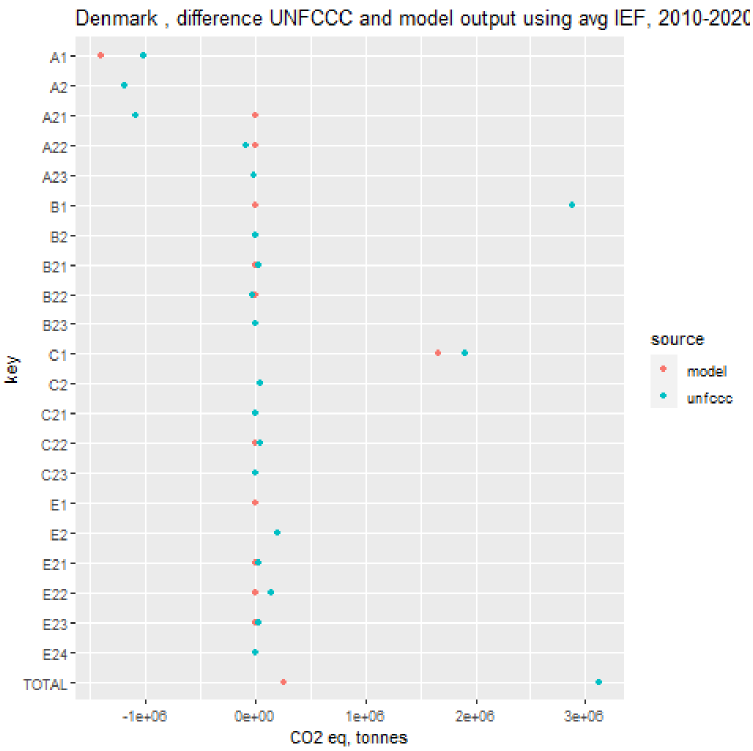


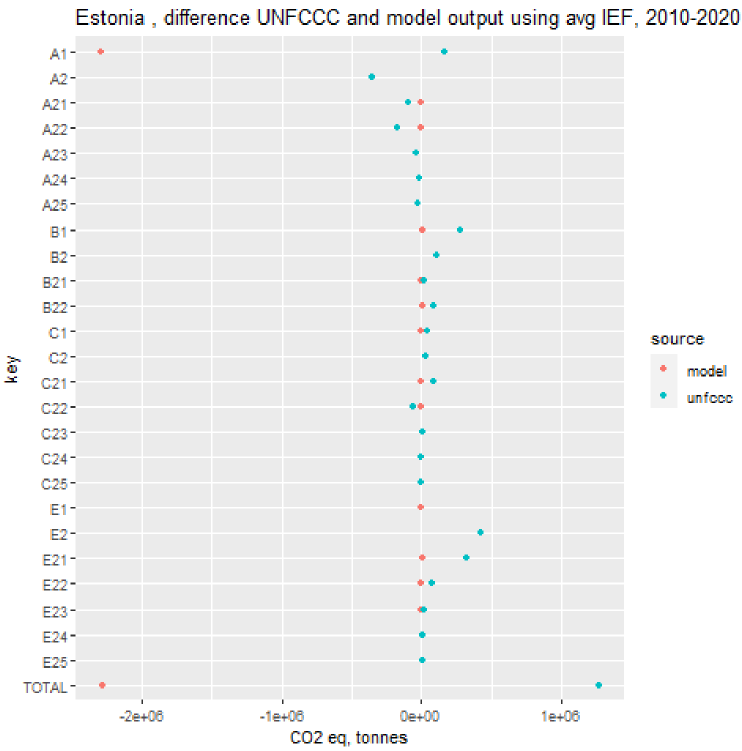

Bulgaria , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A25
B1
B2
B21
B22
C1
C2
C21
C22
C25
E1
E2
E21
E22
E23
E25
TOTAL
key
-1.0e+07
-7.5e+06
-5.0e+06
-2.5e+06
0.0e+00
CO2 eq, tonnes
source
model
unfccc

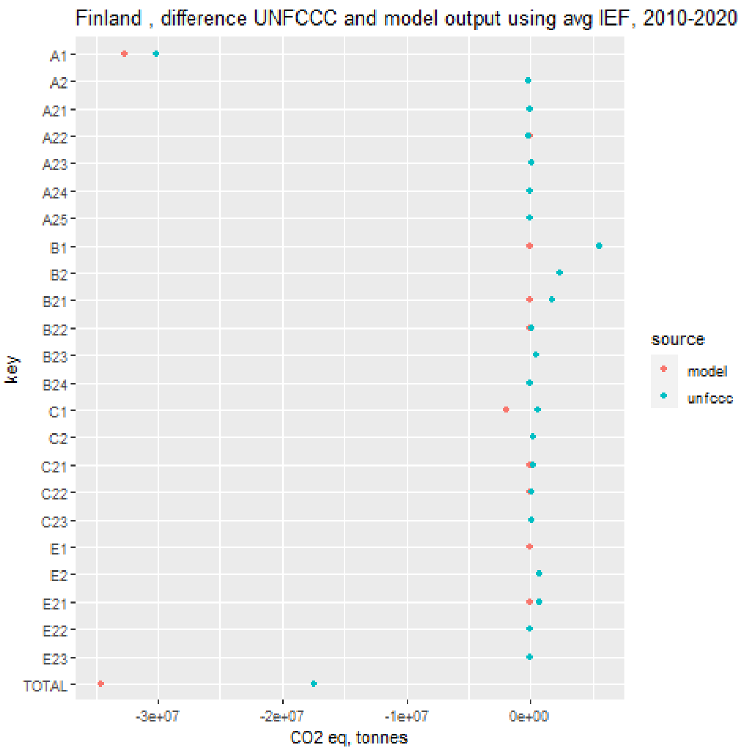

Croatia , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
B1
B2
B21
B22
C1
C2
C21
C22
E1
E2
E21
E22
E23
E24
TOTAL
key
-6e+06
-4e+06
-2e+06
0e+00
CO2 eq, tonnes
source
model
unfccc

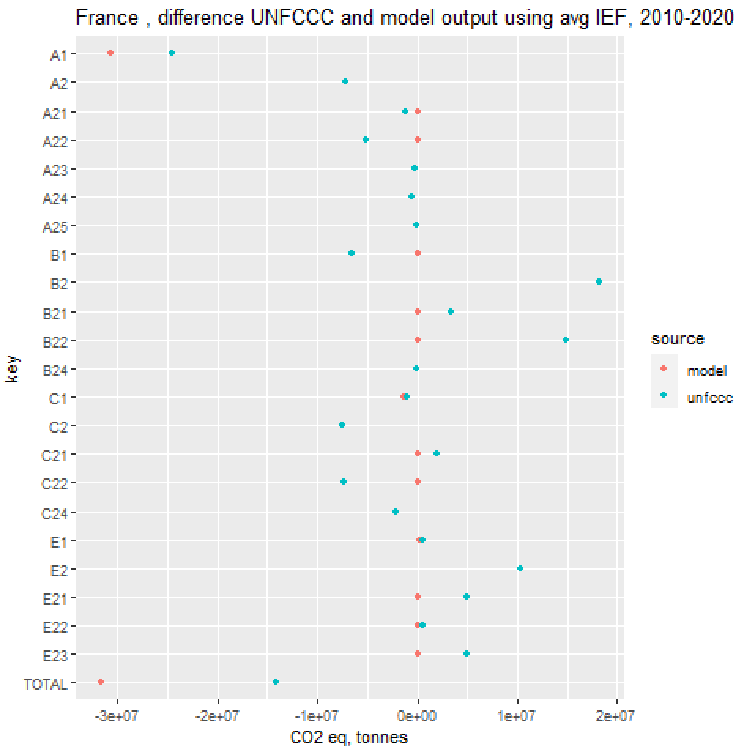

Cyprus , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A24
B1
B2
B21
B22
B24
B25
C1
C2
C21
C22
C24
E1
E2
E21
E22
E23
E24
TOTAL
key
-4e+05
-2e+05
0e+00
CO2 eq, tonnes
source
model
unfccc

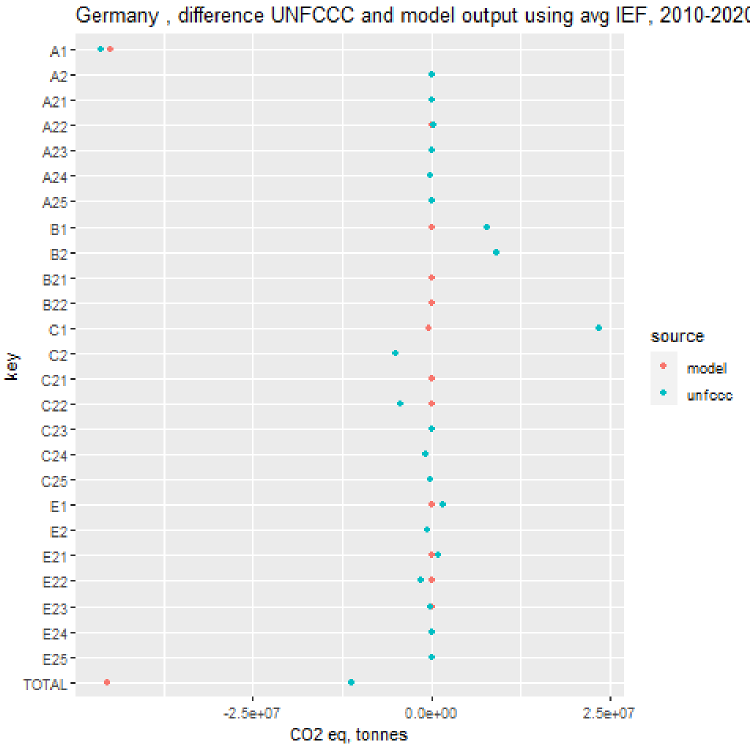

Czech Republic , difference UNFCCC and model output using avg IEF, 201
A1
A2
A21
A22
A23
A24
B1
B2
B21
B22
B23
B24
C1
C2
C21
C22
C23
C24
E1
E2
E21
E22
E23
TOTAL
key
0.0e+00
5.0e+06
1.0e+07
1.5e+07
CO2 eq, tonnes
source
model
unfccc

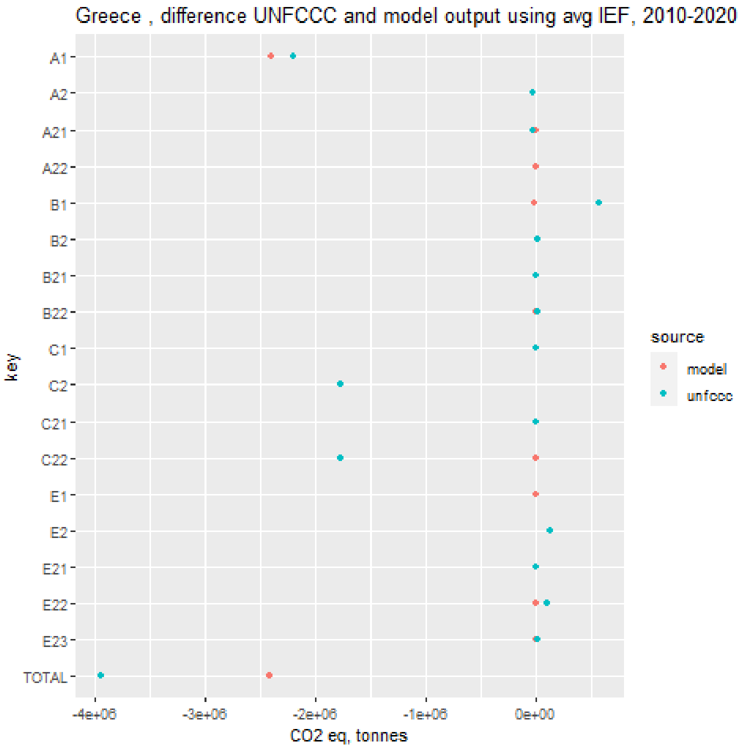

Denmark , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
B1
B2
B21
B22
B23
C1
C2
C21
C22
C23
E1
E2
E21
E22
E23
E24
TOTAL
key
-1e+06
0e+00
1e+06
2e+06
3e+06
CO2 eq, tonnes
source
model
unfccc

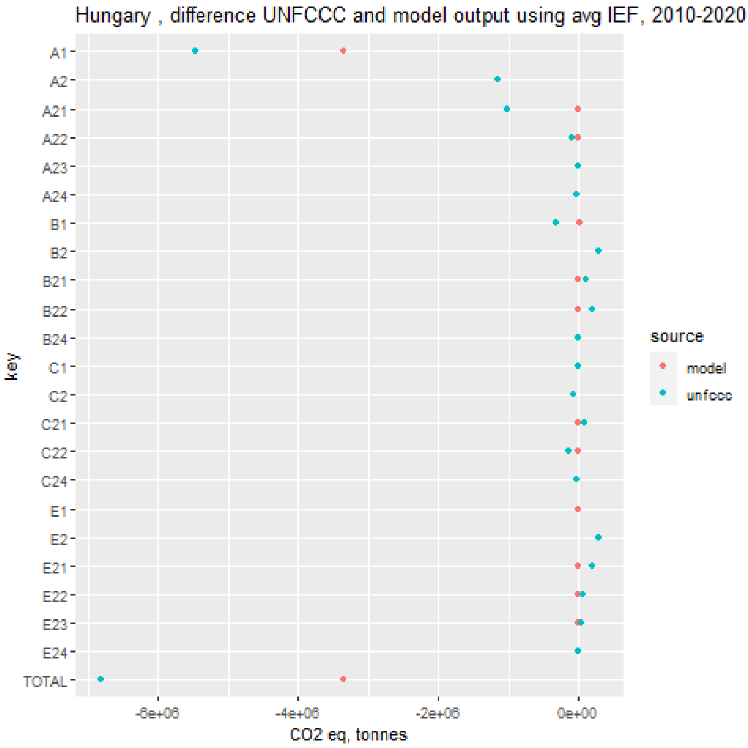

Estonia , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
E25
TOTAL
key
-2e+06
-1e+06
0e+00
1e+06
CO2 eq, tonnes
source
model
unfccc

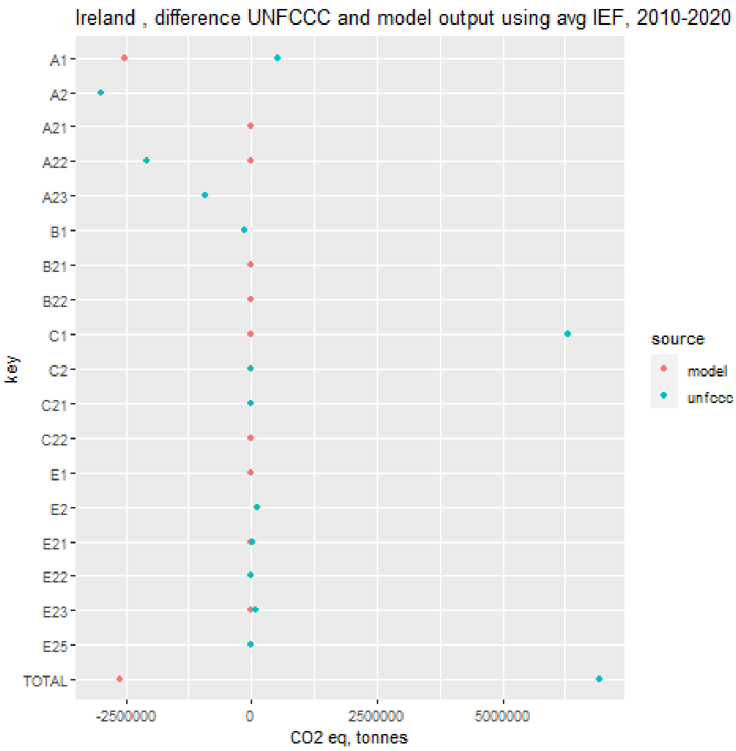

Finland , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B23
B24
C1
C2
C21
C22
C23
E1
E2
E21
E22
E23
TOTAL
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc

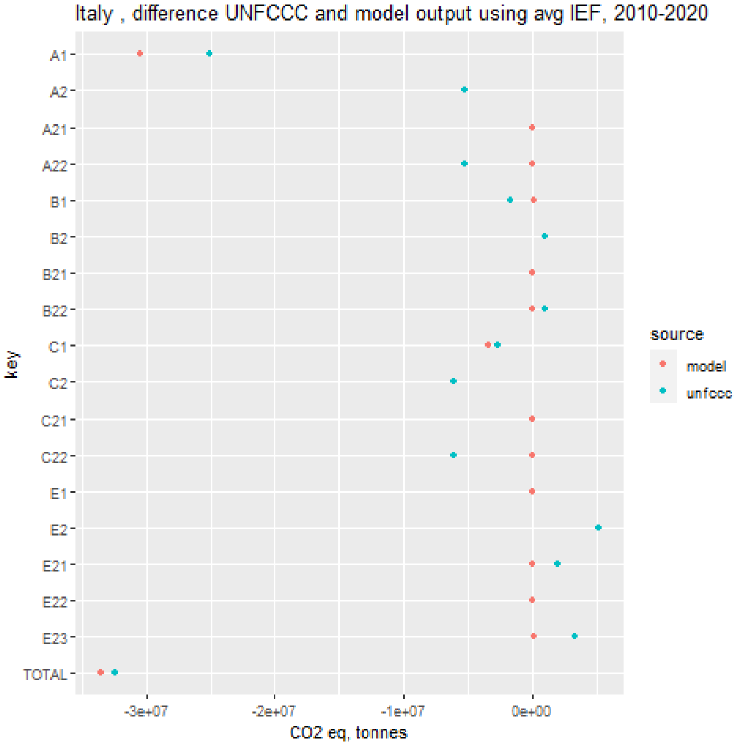

France , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B24
C1
C2
C21
C22
C24
E1
E2
E21
E22
E23
TOTAL
-3e+07
-2e+07
-1e+07
0e+00
1e+07
2e+07
CO2 eq, tonnes
source
model
unfccc

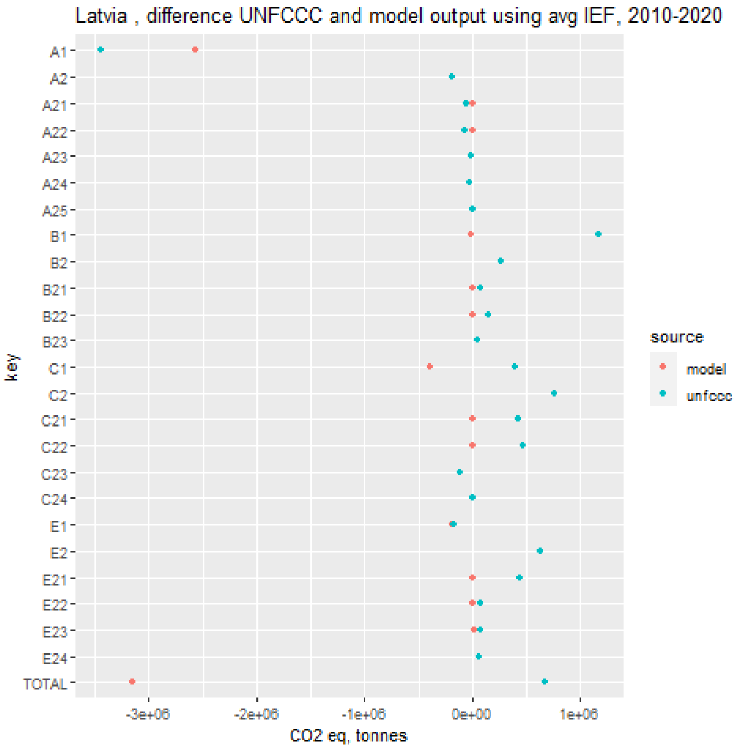

Germany , difference UNFCCC and model output using avg IEF, 2010-202(
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
E25
TOTAL
key
-2.5e+07
0.0e+00
2.5e+07
CO2 eq, tonnes
source
model
unfccc

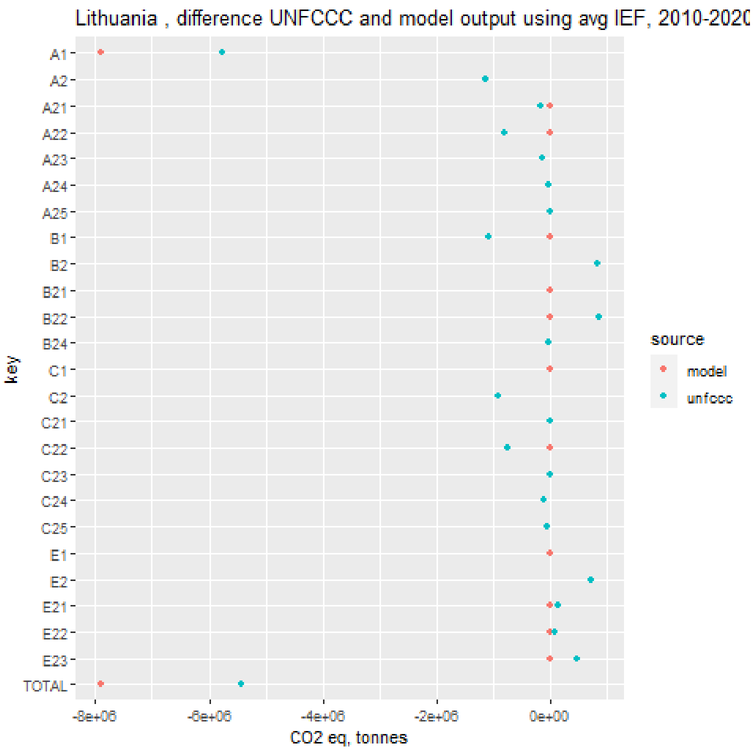

Greece , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
B1
B2
B21
B22
C1
C2
C21
C22
E1
E2
E21
E22
E23
TOTAL
key
-4e+06
-3e+06
-2e+06
-1e+06
0e+00
CO2 eq, tonnes
source
model
unfccc


Hungary , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
A24
B1
B2
B21
B22
B24
C1
C2
C21
C22
C24
E1
E2
E21
E22
E23
E24
TOTAL
key
-6e+06
-4e+06
-2e+06
0e+00
CO2 eq, tonnes
source
model
unfccc

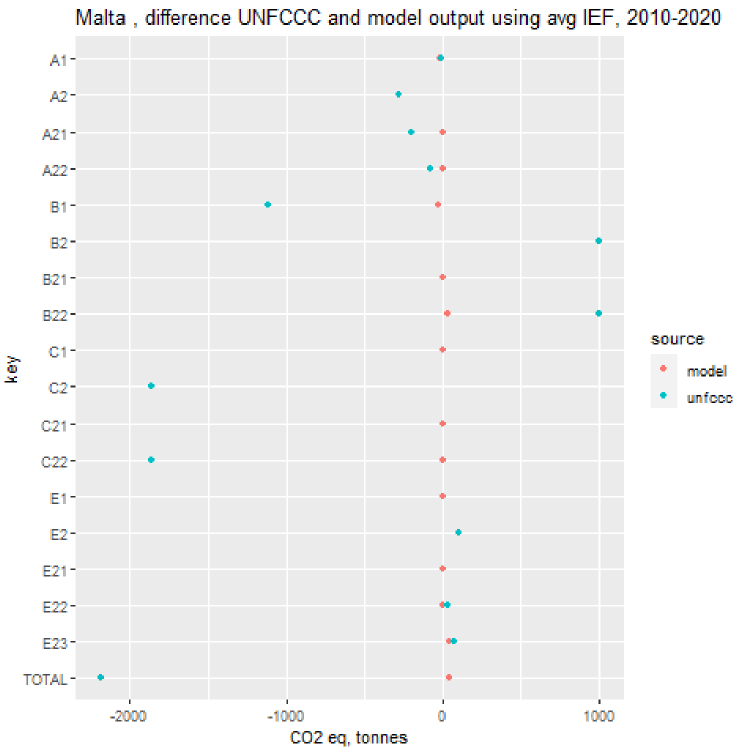

Ireland , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
B1
B21
B22
C1
C2
C21
C22
E1
E2
E21
E22
E23
E25
TOTAL
key
-2500000
0
2500000
5000000
CO2 eq, tonnes
source
model
unfccc


Italy , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
B1
B2
B21
B22
C1
C2
C21
C22
E1
E2
E21
E22
E23
TOTAL
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc

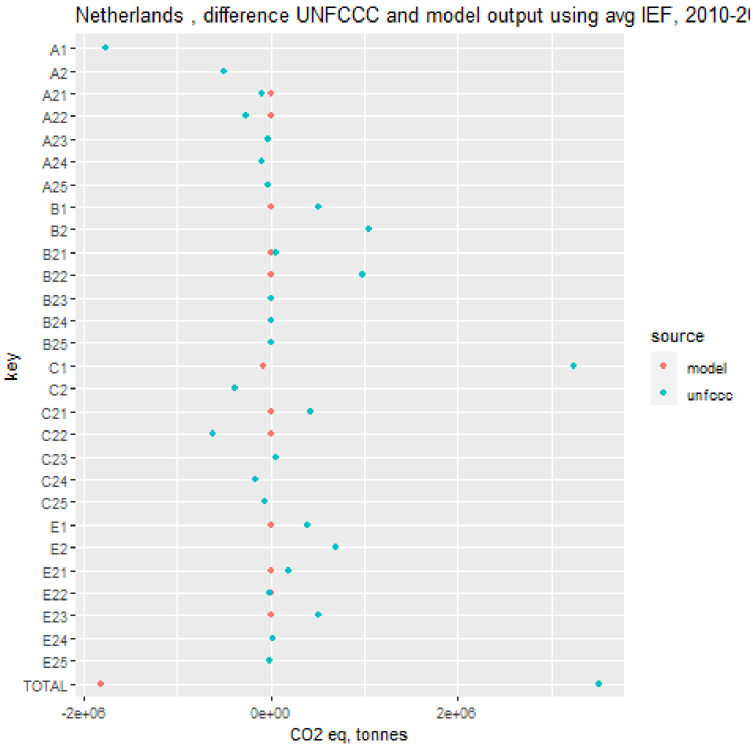

Latvia , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B23
C1
C2
C21
C22
C23
C24
E1
E2
E21
E22
E23
E24
TOTAL
-3e+06
-2e+06
-1e+06
0e+00
1e+06
CO2 eq, tonnes
source
model
unfccc

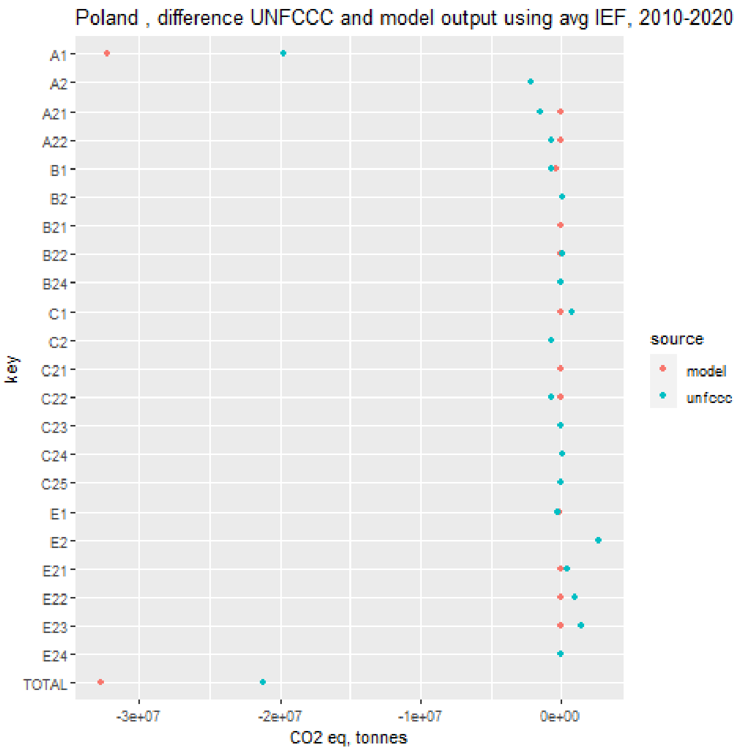


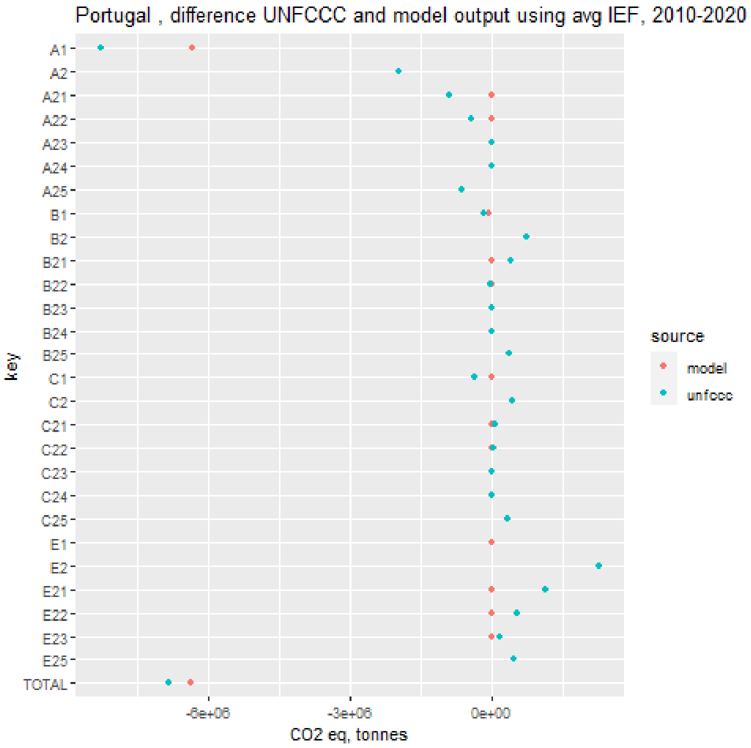
Lithuania , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B24
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
TOTAL
key
-8e+06
-6e+06
-4e+06
-2e+06
0e+00
CO2 eq, tonnes
source
model
unfccc



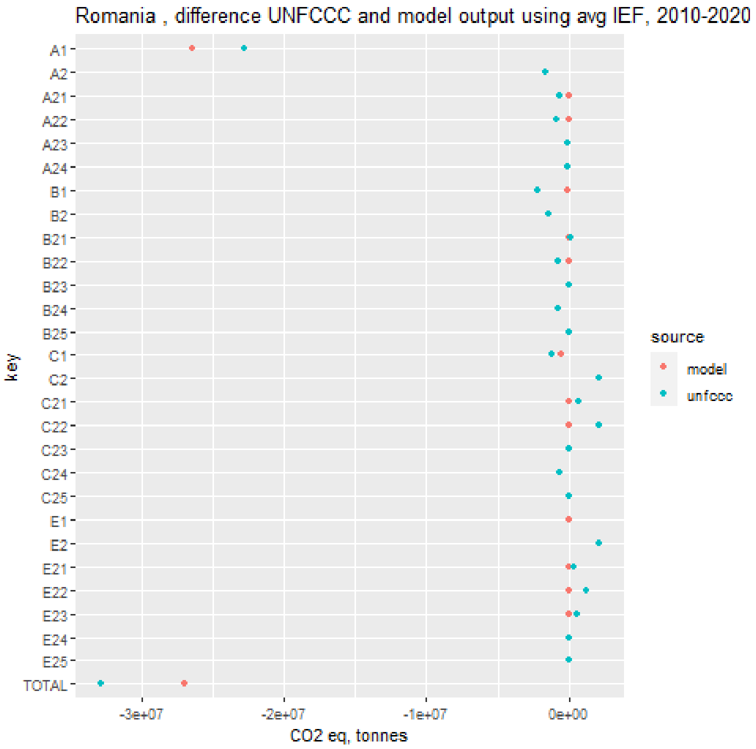
Malta , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
B1
B2
B21
B22
C1
C2
C21
C22
E1
E2
E21
E22
E23
TOTAL
key
-2000
-1000
0
1000
CO2 eq, tonnes
source
model
unfccc


Netherlands , difference UNFCCC and model output using avg IEF, 2010-2(
key
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B23
B24
B25
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
E25
TOTAL
-2e+06
0e+00
2e+06
CO2 eq, tonnes
source
model
unfccc

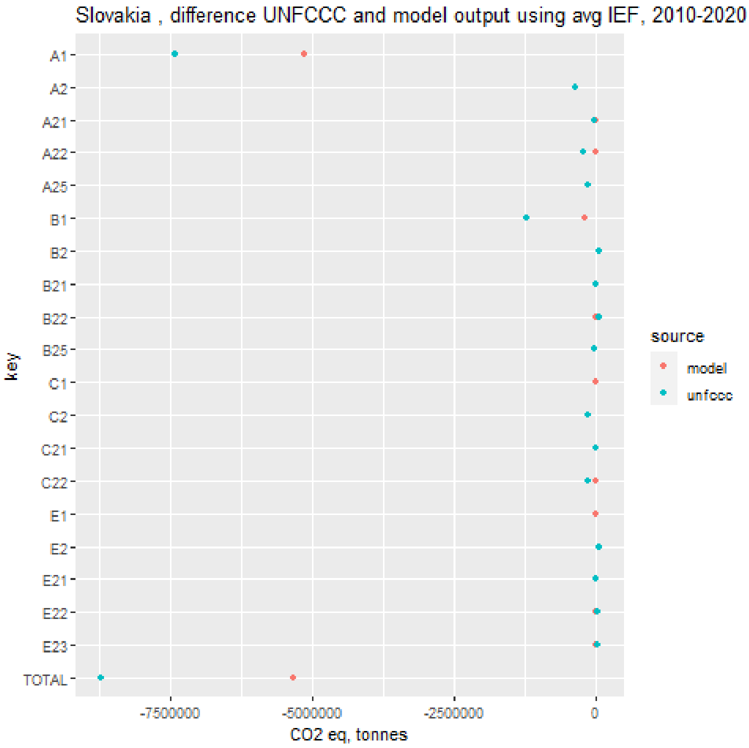

Poland , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
B1
B2
B21
B22
B24
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
TOTAL
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc

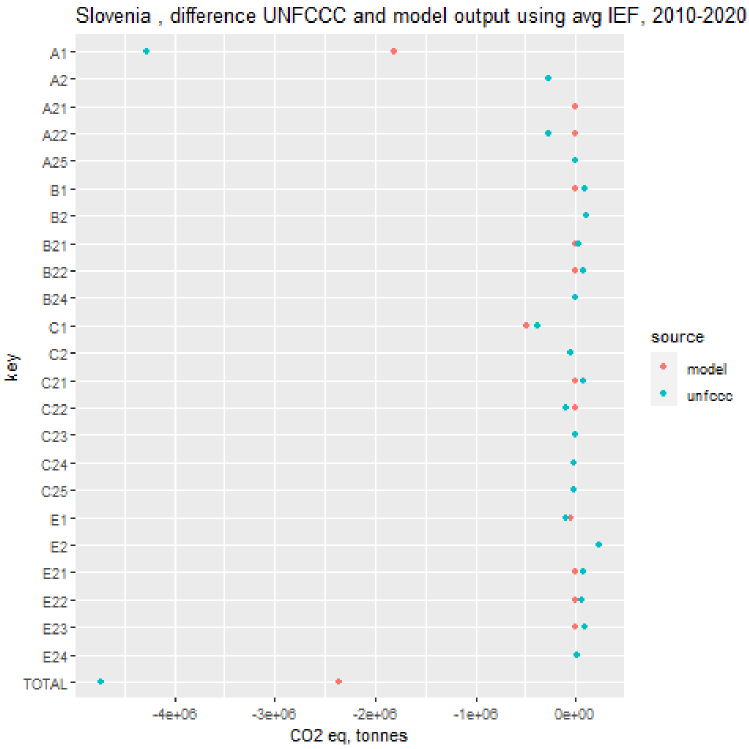


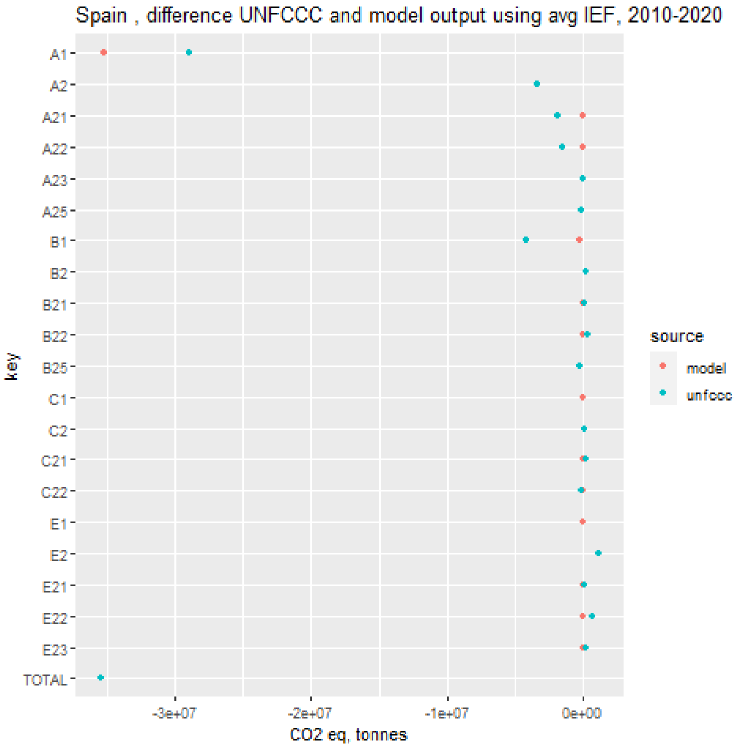
Portugal , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B23
B24
B25
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E25
TOTAL
key
-6e+06
-3e+06
0e+00
CO2 eq, tonnes
source
model
unfccc

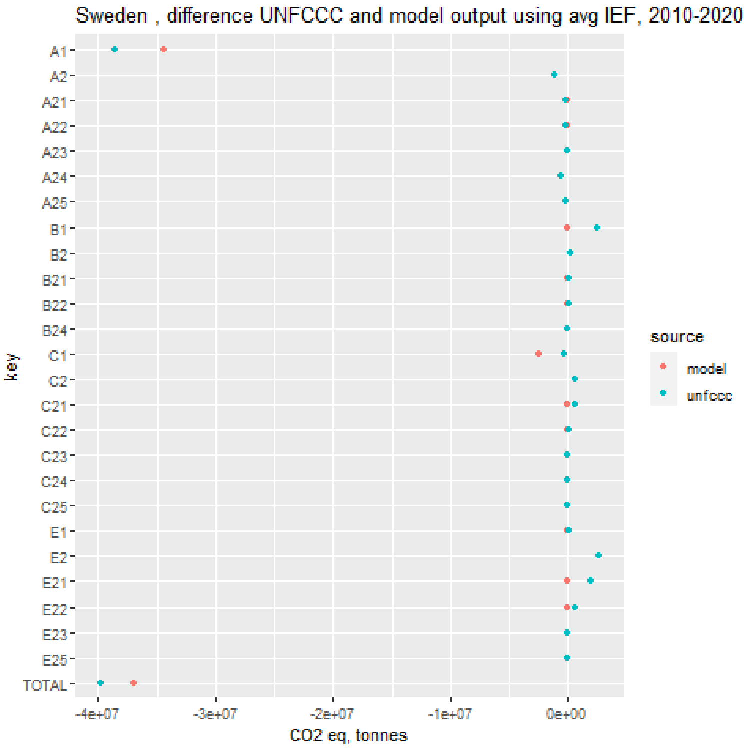


Romania , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A23
A24
B1
B2
B21
B22
B23
B24
B25
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
E25
TOTAL
key
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc


Slovakia , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A25
B1
B2
B21
B22
B25
C1
C2
C21
C22
E1
E2
E21
E22
E23
TOTAL
key
-7500000
-5000000
-2500000
0
CO2 eq, tonnes
source
model
unfccc


Slovenia , difference UNFCCC and model output using avg IEF, 2010-2020
A1
A2
A21
A22
A25
B1
B2
B21
B22
B24
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E24
TOTAL
key
-4e+06
-3e+06
-2e+06
-1e+06
0e+00
CO2 eq, tonnes
source
model
unfccc


Spain , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
A23
A25
B1
B2
B21
B22
B25
C1
C2
C21
C22
E1
E2
E21
E22
E23
TOTAL
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc


Sweden , difference UNFCCC and model output using avg IEF, 2010-2020
key
A1
A2
A21
A22
A23
A24
A25
B1
B2
B21
B22
B24
C1
C2
C21
C22
C23
C24
C25
E1
E2
E21
E22
E23
E25
TOTAL
-4e+07
-3e+07
-2e+07
-1e+07
0e+00
CO2 eq, tonnes
source
model
unfccc

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