Article

Comparing Reported Forest Biomass Gains And Losses In European And Global Datasets

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Received: date; Accepted: date; Published: date

Abstract: Net CO2 emissions and sequestration from European forests are the result of removal and growth of flora. To arrive at aggregated measurements of these processes at a country's level, local observations of increments and harvest rates are up-scaled to national forest areas. Each country releases these statistics through their individual National Forest Inventory using their particular definitions and methodologies. In addition, five international processes deal with the harmonization and comparability of such forest datasets in Europe, namely the IPCC, SOEF, FAOSTAT, HPFFRE, FRA (definitions follow in the article). In this study, we retrieved living biomass dynamics from each of these sources for 27 European Union member states. To demonstrate the reproducibility of our method, we release an open source python package that allows for automated data retrieval and analysis, as new data becomes available. The comparison of the published values shows discrepancies in the magnitude of forest biomass changes for several countries. In some cases, the direction of these changes also differ between sources. The scarcity of the data provided, along with the low spatial resolution, forbids the creation or calibration of a pan-European forest dynamics model, which could ultimately be used to simulate future scenarios and support policy decisions. To attain these goals, an improvement in forest data availability and harmonization is needed.

Keywords: data harvesting; forest modeling; forest growth; macroecology; public data source comparison

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1. Introduction

Forests consist of the largest terrestrial ecosystems that actively store carbon in living biomass. The sequestration effect is a highly relevant topic in the context of climate change mitigation. Quantifying the magnitude of this effect remains a very active research topic [1]. In addition, forests are an important source of raw materials and renewable energy. For instance, substituting fossil-based materials with forest products provides additional climate mitigation benefits [2,3]. Also, as an integral ecosystem, forests provide countless benefits such as biodiversity habitats and recreation services.

In this context, researchers build models and run scenarios that simulate the synergies and trade-offs between these different demands that are made on forest ecosystems [4,5]. Scenarios and models are generally parametrized or trained to reproduce historical developments. As such, a prerequisite for the calibration of a model is to obtain precise and wide ranging data about the current and historical state of forests, as well as records of silvicultural practices. At the minimum these should include the explanatory variables of growth/yield and harvest models, i.e. forested area, species composition, increments and harvest rates.

National Forest Inventories (NFI) make data directly available for each European country individually through their websites. The direct use of NFI data would certainly offer a high level of detail and number of modeling features such as age breakdown and species composition. However, we were not able to use these data sources for the following reasons: (i) It would require parsing dozens of different websites which each have different data formats and are written in different languages. (ii)

The variables of interest have different definitions in each country and one does not have access to the process that links individual plot measurements to country-wide inventory data. (iii) The required harmonization processes are out of the scope of this paper and can only be performed with a deep knowledge of national particularities. Before we move on to international datasets, the following paragraph mentions a few harmonization efforts.

The need to improve comparability has led NFIs to organise several harmonization projects, notably the COST action *usewood* [6] and the Distributed, Integrated and Harmonized Forest Information for Bioeconomy Outlooks (DIABOLO) project (one of the data sources mentioned below). Since 2012, the Joint Research Centre is participating in a "Framework Contract for the provision of forest data and services in support of the European Forest Data Centre" with the European network of NFIs (ENFIN). Until now, framework contracts have focused on the harmonization of forest area and biomass stock. Although it should be noted that the present study is not related and that it focuses on the dynamic aspects.

Now coming back to our analysis. We compared international data sources that offer information on forest biomass dynamics, provided the source in question includes a similarly formatted dataset for every one of the 27 EU member states. All the data acquired by these external sources originates at the individual NFIs, as they are the ones who prepare the values to fit inside the standardized reporting format of international organizations. Every country has developed its own methods to make their measurements conform to the questionnaires they receive. Typically, when there is a higher level of detail available at the national level, the data is summarized and filtered to fit the spreadsheet to be used. Conversely, when a lower level of detail is collected at the national level as compared to what is requested, data expansion is carried out through estimations [6]. The data that we examine in our study is the outcome of these aggregation and interpolation processes performed by each country when preparing their reply to international surveys.

The following five public sources cover all 27 EU member states simultaneously and in a semi-unified format:

1. IPCC: Intergovernmental Panel on Climate Change.
2. SOEF: State of European Forests.
3. FAOSTAT: Food and Agriculture Organization Statistics.
4. HPFFRE: Harmonized projections of future forest resources in Europe.
5. FRA: Forest Resource Assessment.

To acquire the data that these sources provide in an automated fashion, we built a software tool circumventing any missing bulk download functionality. Furthermore, we provided yet another level of standardization on top of what the international organizations do, reformatting and concatenating the measurements so as to enable the comparison of the different datasets amongst each other.

As to be expected, each source uses a different definition for what is considered to be forested land. This is caused, in part, by each organization being heavily shaped by different policy focuses. On top of differences in forest areas, each country has its particular way of measuring biomass dynamics. For instance, some sources report only on volumes of stems while others report only on masses of whole trees (including roots), hindering comparison.

Still, all forest information sources share the same fundamental principles. In essence, the state of today's forests is the result of past growth and disturbances. By definition, tree growth affects the stock of living biomass positively (gains) and disturbances affect it negatively (losses). Disturbances are further distinguished in anthropogenic disturbances (harvest) and natural disturbances (storms, fire, pathogens).

Changes in biomass volume through time can generally be described by the difference between increments (in green) and fellings (in red) visible in figure 1. The gross increment box corresponds to all the above ground biomass growth. It was given a formal definition during the COST action *usewood* [6]:

"Gross annual increment is the average annual stem volume increment of living trees over a specified area during the reference period. The stem volume increment includes the over-bark increment from the stump height to and including the stem top of trees with a diameter at breast height of more than 0 cm (height of more than 1.30 m). Branches are excluded. Included is the stem volume increment of trees which have been felled or die during the reference period."

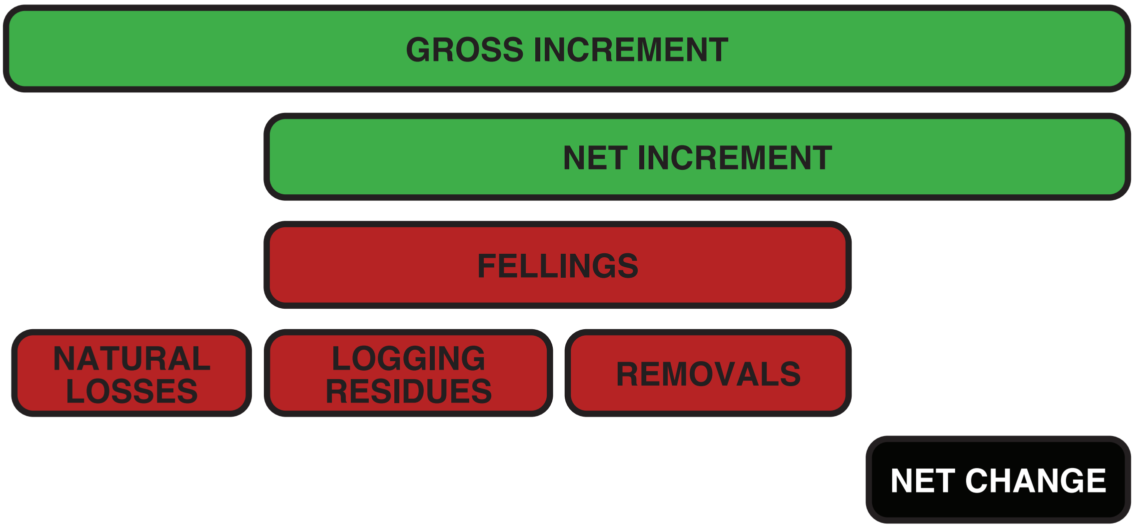


Figure 1. This diagram shows the schematic composition of increment and fellings. It was reproduced from the "State of Europe Forests 2015" report [7].

As the figure shows, the net increment is the gross increment minus natural losses. On the loss side, the removal box has its definition in [6] as:

"Wood lost from growing stock or standing dead trees due to fellings or natural losses between *t1* and *t2* which has been immediately transported out of forest."

By crossing these different datasets amongst each other, we were able to compare biomass growth and disturbances albeit at a very aggregated level. These metrics can be used to asses forest dynamics models against other published representations of historical dynamics. In other words, we prepared aggregates which should be useful for checking whether a model reproduces the general biomass growth and disturbance trends or whether it diverges from official figures.

In contrast to forests in the boreal or tropical zones, a majority of Europe's forest are managed. As countries have close to 90% of their forest area available for wood supply (see table A1), it makes sense to compare biomass dynamics across these sources even though they have a different forest definition.

There is a need to facilitate exchange between scientific communities. For example, [8] encourages collaboration between scientists contributing to the IPCC assessment reports and scientists contributing to the greenhouse gas inventory reports. In a similar vein, [9] encourages data integration between sources to provide "detailed information at large spatial and long temporal scales that can be used in different modeling frameworks".

Finally, advances in remote sensing are changing the playing field. Forest dynamics modeling can only provide meaningful information when it is calibrated with ground data. Because of the high cost of data collection, inventory data is scarce with a periodicity of 5 to 10 years and a spatial resolution limited to a few hundred or a few thousand sample plots per country. Information gained from these sample plots is then extrapolated to the area of a whole country. In conjunction, airborne and space-based sensors complement ground data by providing repeated measurements over wide areas.

However remote sensing observations from satellites and planes do not measure biomass directly. They measure various signals in the electromagnetic spectrum which are indicators of biomass stock (tree structure) or biological processes (photosynthesis). The temporal and spatial resolution of remote sensing methods has recently increased dramatically, with measurements available every year or even at a higher frequency and down to a spatial resolution of 30 meters [10]. The detection of land use changes from forestry to agriculture is now performed routinely with a good accuracy at the global level. In permanently forested areas however, current remote sensing maps provide static information on the presence or absence of forest cover. Within a forested pixel, biomass has a fixed value [11]. When biomass is present, it is considered to be at a stable state without any notion of fluxes (input and outputs). Indeed, remote sensing based detection of tree growth or small scale biomass loss remains highly uncertain [12].

In contrast to land use changes happening at the global scale, in EU countries, tree cover changes by less than 1% per year [7]. In other words, the vast majority of biomass dynamics and related carbon fluxes happens in forest land remaining forest land. For the foreseeable future, ground measurement will remain the most precise source of information on slow growth processes. And this is where aggregating inventory data remains crucial.

2. Materials and Methods

2.1. Data sources

We set out to retrieve data concerning forests on the European continent and to include only data sources that would provide measurements on multiple countries concurrently in a harmonized format. We focused on obtaining measurements expressing the amount of forested areas as well as growth and harvest rates.

There were several public data sources accessible online that provided these types of information in various forms and levels of granularity. Five data sources were identified and included in this study. Each one is detailed in the sections below.

We chose to include 27 countries in the analysis. Namely, all past and present European member states with the exception of Malta which has less than 400 hectares of forested land [7]:

> Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom.

Not all countries were present in each data source, unfortunately.

2.1.1. IPCC

The "Intergovernmental Panel on Climate Change" (IPCC) is the United Nations body responsible for assessing the science related to climate change. An integral part of this process is the collection of emission estimates for each participating country. Under the name "National Inventory Submissions", they provide a common reporting format that assembles data on "all greenhouse gas (GHG) emissions and removals, implied emission factors and activity data" [13].

To retrieve data from the IPCC National Inventory Submission website, we first parsed the HTML table found at https://tinyurl.com/y474yu9e and selected the appropriate link for each country. For countries where several links were available, we picked the files that matched the country's ISO3 code. Next, each ZIP file was downloaded and uncompressed, producing one XLS file per country per year, for a total of 770 distinct files.

As the IPCC website currently blocks automated requests with the use of the "Incapsula" software solution, the pages and excel files were downloaded by running a headless browser with the "gecko-driver" and "selenium" [14] technologies to bypass their restrictions. In the case of the

GHG inventory reports, the IPCC regretfully did not offer either a bulk download option nor an authenticated API to access their data. As a side effect of the anti-DDoS techniques employed, their current interface is only practical for the manual retrieval of specific measurements. It actively prevents automated data retrieval and therefore impairs scientists from performing wide-ranging analyses.

We then developed routines that parsed the resulting excel sheets. We were interested in the carbon stock changes in forest biomass reported in "Table 4.a Sectoral background data for land use, land-use change and forestry - forest land" and focused only on forest land that remained as forest land. From this table, we used the columns titled "Carbon stock change in living biomass" subdivided in gains, losses and net change.

Countries varied in the structure of the aforementioned table and the number of rows provided. For instance, some countries used the different rows to distinguish coniferous and deciduous forest land while other countries had no such rows. Other times, the additional rows were used to distinguish between categories such as mainland versus overseas territories instead of forest types. This is due to the fact that the IPCC common reporting format does not impose a specific subdivision of the forest land category, and many countries add or remove rows at will, specifying custom information or not. This often prevents automated parsing of all countries. Fortunately, the code automatically identifies the length of the contained table. However it may require some manual intervention to adapt the software to a new country's data structure as it becomes available.

2.1.2. SOEF

The "Ministerial Conference on the Protection of Forests in Europe" [7] regularly publishes a "State of European Forests Report" (SOEF). This report includes the aggregation of NFI data and is made possible by a common reporting standard. Each countries' submissions are accessible in a database at https://dbsoef.foresteurope.org/.

To retrieve the data concerning all countries, we parsed the HTML contents of the drop-down menu found at https://dbsoef.foresteurope.org/downloadStatistics.jsp and automated the download of all excel files based on the links extracted.

Following the download, every country's data was contained in a single Excel file. For each file, we parsed four tables:

- **Table 1.1a**: Forest area.
- **Table 1.1b**: Forest area by forest types.
- **Table 1.2b**: Growing stock by forest types.
- **Table 3.1**: Increment and fellings.

This was enabled by developing a flexible table parser that can identify the start and end rows within each different file to streamline the process and avoid manual interventions. This is necessary as the excel files differed greatly between countries and do not seem to be post-processed or corrected by SOEF themselves. This is made evident by the presence of calculations and temporary notes written in local languages next to the tables (in usually empty cells), as well as other typos, mistakes and inconsistencies.

To help with ease of access and comparison, column titles were renamed and units were converted to SI standards where possible.

The main table of interest in the SOEF source is the increment and fellings table. We used table 1.1b and 1.2b to normalize the stock volume per area and per forest type. This was later used as a threshold to select the appropriate biomass expansion factors and the root to shoot ratios. Further explanations are below in the section on conversion to mass.

2.1.3. FAOSTAT

FAOSTAT is the corporate statistical database of the "Food and Agriculture Organization of the United Nations". The `forest_puller` software downloads data for forest area from http://www.fao.

org/faostat/en/#data/GF while the data for wood removals is downloaded from http://www.fao.org/faostat/en/#data/FO. Both datasets were obtained by picking the "All Data Normalized" option from the "Bulk download" sidebar and retrieving the appropriate CSV file from the archive.

In the case of the "Forest Land" dataset, we filtered the data by picking rows where "element" was equal to "area" and where "item" was equal to "forest land".

In the case of the "Forestry Production and Trade" dataset, wood removals were determined by picking the rows where "element" was equal to "production quantity". Furthermore, we selected all the "roundwood" and "wood fuel" items, whether they were coniferous or non-coniferous.

2.1.4. FRA

FRA stands for "Forest Resource Assessment" and is a report that is published every five years by the FAO (same organization as FAOSTAT). This report provides global information on forest area, stock and additional sustainability indicators. There is no information on stock dynamics, i.e. increments and fellings in this data source.

The software produced downloads two datasets with ID "T01FO000.csv" and "T06FO000.csv" from the "CountrySTAT" platform.

The first is titled "Extent of forest and other wooded land" and is located at http://countrystat.org/home.aspx?c=FOR&tr=1. We filtered this dataset by selecting rows where "category" was equal to "forest" to obtain the total area for each country.

The second is titled "Growing stock by forest/other wooded land" and is located at http://countrystat.org/home.aspx?c=FOR&tr=4. We filtered this dataset by selecting rows where "category" was equal to "total growing stock" and "land type" was equal to "forest" to retrieve the standing stock in each country.

As usual, we renamed column titles and converted the units to be comparable between different sources.

2.1.5. HPFFRE

HPFFRE stands for "Harmonized projections of future forest resources in Europe" and is a publication by Vauhkonen et al. 2019 [15] which contains forest data for 21 of the 27 countries studied in this analysis. It was released as part of a work package in the Diabolo project [16] and is available at https://doi.org/10.5061/dryad.4t880qh.

This dataset is provided as a single CSV file from the supplementary information of the publication and was easy to parse. We selected values from the first scenario and used the historical period only, discarding all future predictions made by the model. We also summed the different categories of availability for wood supply together (FAWS, FNAWS, FRAWS). This gave us access to both to the total forested area and to the standing stock for each country.

2.2. Conversion to mass

Though all data sources describe the same phenomena of tree growth and removal, not all use the same definitions or units. The IPCC data source provides measures of carbon stock change in the living biomass using tonnes of carbon per hectare as units. In their case, the term biomass includes the tree stem, the branches and the roots. The same unit is used for both increments and removals.

Meanwhile, SOEF provides increment and felling volumes using cubic meters per hectare and including only the stem of the tree (over bark). FAOSTAT describes round-wood removals measurement as "all quantities of wood felled and removed from the forest and other wooded land or other felling sites. They are measured in cubic meters under bark (without bark)". Lastly, HPFFRE expresses the dynamics in "Stemwood volume measured over bark expressed as unit area volume". It further specifies: "Total stemwood volume measured over bark. Part of tree stem from the felling cut to the tree top with the branches removed, including bark". A summary of the different units used is provided in table 1.

Table 1. Overview of the variables of interest in each dataset.

Source	area	stock	gains	losses	Units
IPCC	x	x	x	x	Biomass in tonnes of carbon
SOEF	x	x	x	x	Stem volume in m3 over bark
FAOSTAT	x			x	Stem volume in m3 under bark
FRA	x	x			Stem volume in m3 over bark
HPFFRE	x	x		x	Stem volume in m3 over bark

As three of the sources (SOEF, FAOSTAT and HPFFRE) report forest dynamics in volume of stem wood (over bark or under bark) while IPCC reports biomass dynamics in tonnes of carbon, for the purposes of comparison, we converted the merchantable volume increment to a carbon biomass gain (including both above and below ground biomass) based on equation 2.10 of the IPCC guidelines [17, chapter two]:

$$G_{mc} = I_v * BCEF_I * (1 + R) * CF \quad (1)$$

Where:

- G_{mc} is the carbon biomass gain expressed in $[kg/ha/year]$.
- I_v is the merchantable volume increment expressed in $[m^3/ha/year]$.
- $BCEF_I$ is the biomass conversion and expansion factor of the annual increment; it accounts for both the density and the expansion of merchantable biomass to above ground biomass. The units are $[kg/m^3]$.
- R is the root to shoot ratio and is unitless.
- CF is the carbon fraction of dry biomass and is unitless.

Similarly, we converted wood removal volumes H_v (H for harvest) to losses in tonnes of carbon L_{mc} according to equation 2.12 of the IPCC guidelines [17, chapter 2] :

$$L_{mc} = H_v * BCEF_R * (1 + R) * CF \quad (2)$$

Where:

- G_{mc} is the carbon biomass loss expressed in $[kg/ha/year]$.
- H_v is the merchantable volume harvest expressed in $[m^3/ha/year]$.
- $BCEF_R$ is the expansion factor of wood and fuelwood removal volume to above-ground biomass removal. The units are $[kg/m^3]$.
- R and CF are the same as in equation 1.

The root to shoot ratio R is available in table 4.4 "ratio of below-ground biomass to above-ground biomass (r)" of the 2006 IPCC guidelines [17]. At the aggregate level, no specifics on forest density by species are given. The only information that is provided to pick the BCEF and R values are the leaf type (coniferous or broadleaved) along with the climatic zone. We allocated each country to one or two climatic zones based on the FAO map of global ecological zones available at http://www.fao.org/3/ad652e/ad652e21.htm.

From the SOEF data, we computed the merchantable biomass stock per area by leaf type and used it as a threshold value to choose the BCEF parameter. We then computed the above ground biomass stock and used it as a new threshold value to choose the R parameter.

Based on the IPCC guidelines chapter four [17], we selected a single value for the carbon fraction of dry matter $CF = 0.47$. This value expresses tonnes of carbon per tonne of dry biomass.

In order to convert the under-bark volumes reported by FAOSTAT to over-bark volumes, we used the average value of 0.88 taken from [18, page 19] under the title "Volume ratio wood/bark plus wood".

Because of the simplifying hypotheses made when choosing the conversion factors, the weight values obtained with this method are approximative and should not to be used for exact comparison purposes.

2.3. Common data format

Compared to other sources, FAOSTAT bulk data is much easier to retrieve and parse through a standard CSV format, avoiding any GUI or dependency on commercial Microsoft technologies, both of which often lead to ill-formatted spreadsheets when employed. The experience FAOSTAT has acquired by providing publicly available agricultural data for decades is apparent when interacting with its platform.

Following the procedure described above for each data source, the results were compiled in a common format for all countries by using the `pandas` python package [**?**] and its `DataFrame` object. This enabled all values to be easily concatenated and arbitrary comparisons quickly performed. For example equations 1 and 2 are visible in the source code of `forest_puller/viz/converted_to_tons.py` line 85 and 87 of commit 6d713d8. Pandas data frames are also compatible with the `matplotlib` library [19] used for the graphs and visualizations.

2.4. Open software

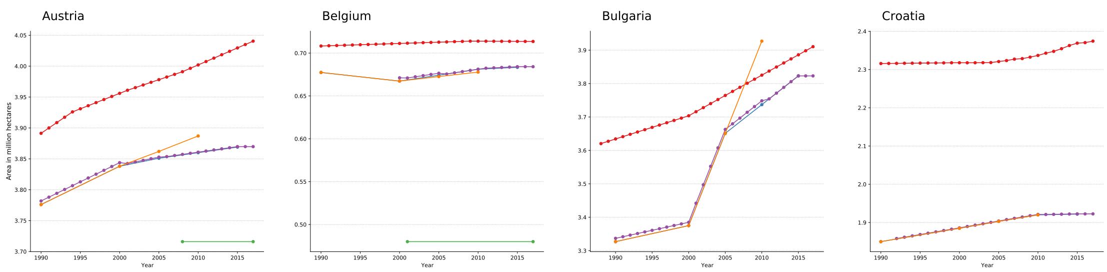
All the software written for the purpose of this publication to download, store, process, parse and visualize the forest data is freely available as a python package under the name `forest_puller`. The package can be installed with the command `pip3 install forest_puller` and the source code is distributed online under the MIT license at https://github.com/xapple/forest_puller. We would like to encourage readers to review and contribute to the software as well as report any issues encountered on the bug tracker. Each source file has ample comments and every routine is documented.

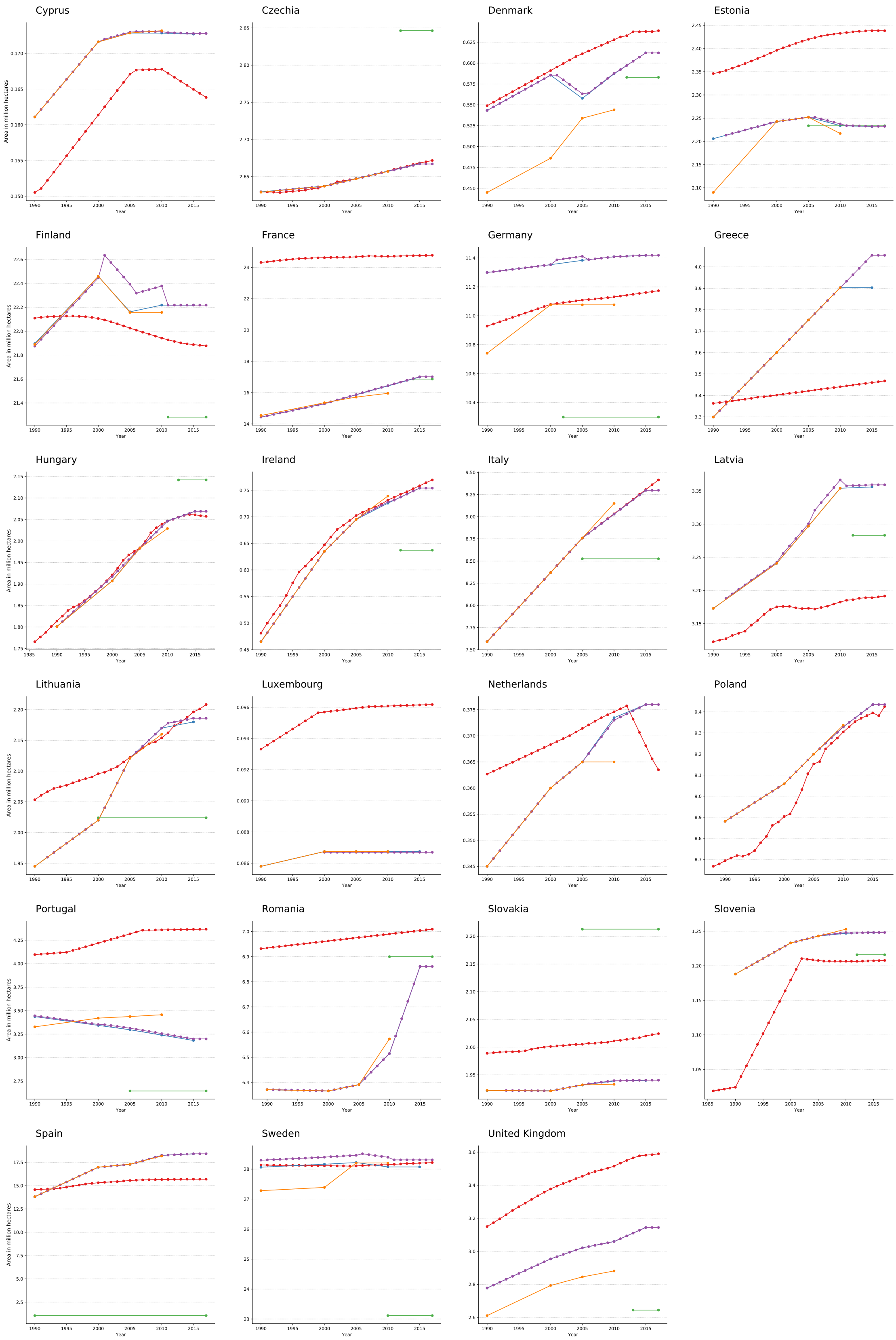
3. Results

We are now able to check whether the five different datasets obtained agree or differ amongst each other.

3.1. Comparison of forest area

The main goal was to compare the changes in biomass volumes. Since these changes are always normalized by the area, it is natural to start comparing forest areas first (figure 2). For SOEF, HPFFRE and FRA, the total forest area excludes other wooded land, i.e. land not defined as forest. The maximum forest area is shown for each country in table 2. In most countries, the total forest area reported by FAOSTAT is identical to the one reported by SOEF. The former has a periodicity of one year while the latter has a periodicity of five years. Additional points in FAOSTAT's yearly data have been obtained by interpolation as is visible in the changes of slope for Denmark and Bulgaria, for example. As the dynamics reported by SOEF and FAOSTAT are highly similar, we will focus on the comparison between the IPCC and SOEF forest areas for the rest of this section.




Cyprus
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Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Ireland
Italy
Latvia
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United Kingdom
Area in million hectares
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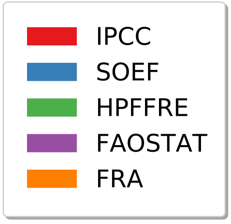


Figure 2. Total forest area in million hectares in the 5 data sources and 27 countries present in the dataset.

Table 2. Maximum forest area (at any year) for each country by sources.

Country	IPCC	SOEF	FAOSTAT	HPFFRE	FRA
AT	4'040'500	3'869'000	3'869'800	3'716'000	3'887'000
BE	713'948	683'400	684'120	480'000	677'800
BG	3'910'384	3'823'000	3'823'000	-	3'927'000
HR	2'374'262	1'922'000	1'922'600	-	1'920'000
CY	167'776	172'851	173'049	-	173'182
CZ	2'671'658	2'667'412	2'667'000	2'846'400	2'657'000
DK	638'816	612'225	612'200	582'847	544'000
EE	2'438'484	2'252'090	2'252'000	2'233'650	2'252'000
FI	22'126'760	22'458'554	22'634'637	21'281'685	22'459'000
FR	24'775'015	16'989'000	17'012'800	16'866'120	15'954'000
DE	11'173'782	11'419'000	11'419'000	10'298'810	11'076'000
GR	3'467'785	3'903'000	4'054'000	-	3'903'000
HU	2'061'432	2'069'130	2'069'000	2'142'000	2'029'000
IE	769'395	754'016	754'016	637'130	739'000
IT	9'414'636	9'297'000	9'297'000	8'525'300	9'149'000
LV	3'191'625	3'356'000	3'366'600	3'283'130	3'354'000
LT	2'208'296	2'180'000	2'186'000	2'024'023	2'160'000
LU	96'176	86'750	86'700	-	86'750
NL	375'744	376'000	376'000	-	365'000
PL	9'425'730	9'435'000	9'435'000	-	9'337'000
PT	4'367'228	3'436'192	3'445'300	2'644'620	3'456'000
RO	7'009'356	6'861'000	6'861'000	6'900'000	6'573'000
SK	2'024'374	1'940'000	1'940'400	2'212'800	1'933'000
SI	1'210'350	1'248'000	1'248'200	1'216'000	1'253'000
ES	15'694'285	18'417'874	18'417'870	1'057'417	18'173'280
SE	28'218'481	28'218'000	28'511'000	23'114'900	28'203'000
GB	3'589'932	3'144'000	3'144'000	2'644'200	2'881'000

In figure 2, four types of patterns emerged: (i) countries for which IPCC and SOEF forest areas are identical: Czechia, Hungary, Ireland, Italy, Sweden, (ii) counties for which the trends are similar but the curves are separated by an offset which could be due to a different forest land definition: Austria, Belgium, Croatia, Cyprus, Germany, Luxembourg, Slovakia, United Kingdom, (iii) countries for which the trends differ only slightly: Bulgaria, Estonia, France (footnote Guyana), Lithuania, Luxembourg, Poland, Portugal, Slovenia and Spain, (iv) countries for which the trends differ markedly: Denmark, Finland, Greece, Latvia, Lithuania, Netherlands, Romania.

Forest dynamics are modeled differently between productive and non-productive forest land. This distinction is made available in the HPFFRE dataset which reports (i) forest available for wood supply, (ii) forest with restricted availability for wood supply, and (iii) forest not available for wood supply. However, in the IPCC data, this distinction is not available for all countries.

3.2. Growth dynamics

National forest inventories typically measure biomass gains in cubic meters of merchantable timber. The purpose of the international processes is to aggregate those gains into comparable figures at the national level. In order to compare other sources with the IPCC, which expresses gains in tonnes of carbon for the total above and below ground biomass, we converted all other sources to tonnes of carbon (see figures 4 and A2). However, conversion factors were not available for all countries, hence figures 3 and A1 are expressed in the original units. Figure 3 compares biomass growth between 1990 and 2015, for a selection of countries. Plots for all countries are available in the appendix, figure A1.

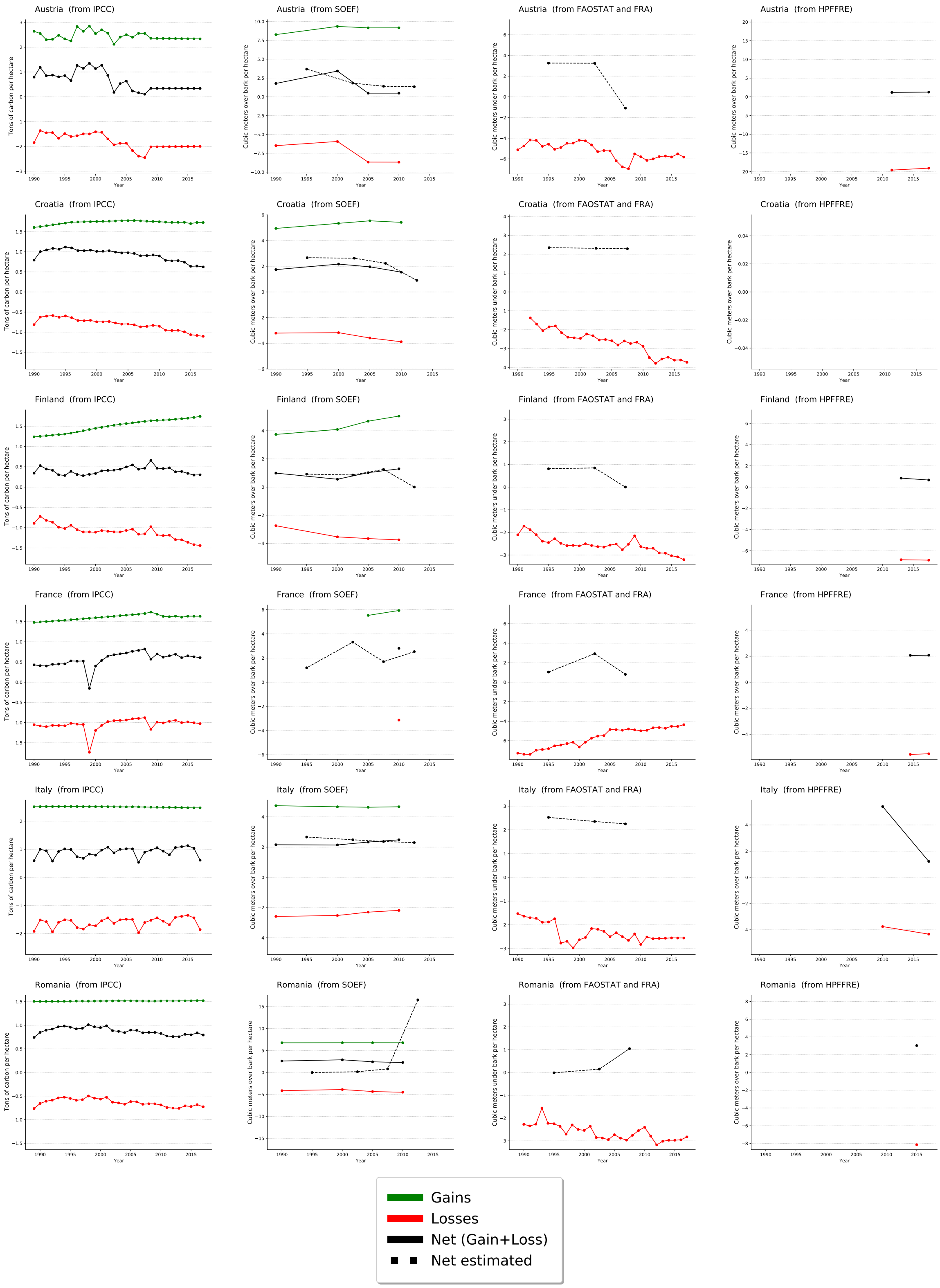


Figure 3. Comparison of the forest dynamics expressed in the original units for a selection of countries.

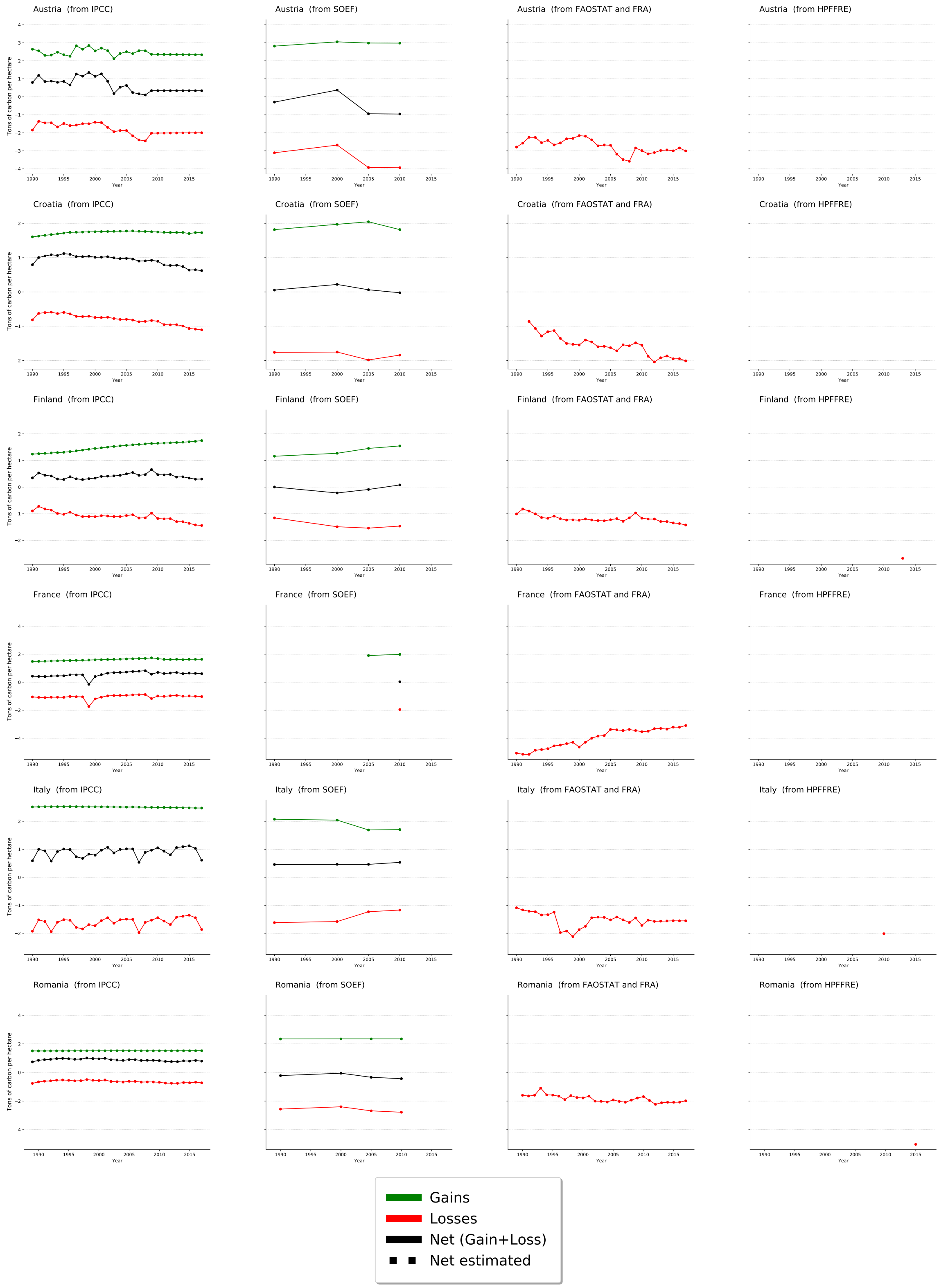


Figure 4. Comparison of the forest dynamics expressed in tonnes of carbon for a selection of countries.

In most countries, biomass gains are stable or slightly increasing over the period. Net increment values are around five to six cubic meters per hectare according to the SOEF data. Corresponding gain values are below two tonnes of carbon per hectare in the IPCC data. The following countries show similar stable or slightly increasing trends both in terms of IPCC gains and SOEF increment values: Austria, Croatia, Finland, France, Italy, Latvia, Poland, Romania, Hungary. However, trends differ for some countries. Indeed, the IPCC gain values are slightly decreasing year over year, while the SOEF data shows increases in gains over the same period of time in Denmark, Netherlands, Slovenia and Lithuania. Other countries do not have enough data points to compare trends.

Germany and Belgium use the stock change approach to report biomass gain values to the IPCC. As a result, the green curve figure A1 has typical step shapes with constant gains for a few years followed by large changes. Other countries use the approach "one inventory plus change" which causes the curve to have more gradual annual changes along a trend.

The following countries have similar biomass gain levels in the IPCC and SOEF after conversion to tonnes of carbon: Austria, Croatia, Cyprus, Finland, France, Latvia, Netherlands. Another comparison provided here are the gains averaged over the whole period available in table 3. We can see that the IPCC gain level is higher than the corresponding SOEF gain in the case of Italy. Conversely, the IPCC gain level is lower than the one found in SOEF for Denmark, Romania, Slovenia.

Table 3. Average gains and losses per hectare by country over the data period available.

	Gains per hectare		Losses per hectare			
Source Country	IPCC	SOEF	FAO	HPFFRE	IPCC	SOEF
AT	2.45	2.96	-2.74	-	-1.81	-3.41
BE	0.56	2.24	-4.60	-4.23	-0.00	-3.05
BG	0.89	-	-1.33	-	-0.02	-
CY	0.24	0.31	-0.09	-	-0.11	-0.26
CZ	2.90	-	-3.18	-	-2.27	-
DE	1.18	-	-	-	-0.02	-
DK	0.64	3.04	-3.94	-	-0.11	-4.66
EE	0.27	-	-2.41	-10.85	-0.00	-
ES	0.57	1.05	-0.82	-	-	-0.96
FI	1.50	1.35	-1.18	-2.67	-1.10	-1.41
FR	1.61	1.95	-3.99	-	-1.04	-1.95
GB	4.19	-	-1.96	-3.47	-3.16	-
GR	0.16	-	-	-	-0.01	-
HR	1.73	1.91	-1.56	-	-0.81	-1.83
HU	0.49	2.39	-3.03	-	-0.02	-3.62
IE	6.52	4.16	-2.59	-	-4.76	-3.66
IT	2.51	1.88	-1.52	-2.01	-1.61	-1.40
LT	0.84	2.86	-2.47	-	-0.20	-4.04
LU	3.14	-	-	-	-1.69	-
LV	2.81	2.73	-2.47	-	-1.98	-3.40
NL	2.45	3.05	-2.97	-	-1.03	-2.87
PL	0.96	2.88	-1.93	-	-	-3.20
PT	1.99	-	-	-	-1.32	-
RO	1.51	2.35	-1.84	-5.03	-0.64	-2.61
SE	0.33	1.32	-1.31	-	-	-2.09
SI	1.09	2.43	-1.51	-	-0.23	-1.36
SK	2.35	-	-2.27	-3.97	-1.47	-

A lower gain value is expected in countries where the IPCC forest area is larger than the SOEF forest area. Since the larger area is likely to include more of the unproductive forest land possessing slow growth rates, this lowers the average growth value.

A comparison in tonnes of carbon is not possible in other countries due to a lack of data in one of the sources or a missing mass conversion factor. Even though the conversion from stem volume increment to biomass gain is approximate, the fact that seven countries have similar values seemed to confirm that the approach is relevant to check the order of magnitude of biomass gains at a national level.

3.3. Disturbances dynamics

Biomass losses are due to the combination of harvest and natural disturbances. At the national level, changes in losses can be due to large fluctuations in economic activity. As an example, in many countries, the impact of the 2008 financial crisis can be observed by a decrease in harvest. Indeed, the red curve moves upward as losses are represented by negative values on the vertical axis (figure 4). Then both types of disturbances can be combined. For instance, large storms or insect outbreaks lead to significant amounts of salvage logging visible in the national harvest statistics. A striking illustration is visible in the losses curves of Austria and Czechia as both countries have been severely hit by storms in recent years. Beyond the issue of combined disturbances, one should remain cautious and remember that more data is collected on harvest volumes and salvage logging simply because of the numerous economic actors involved. On the other hand, biomass losses due to natural disturbances are measured with very high uncertainty.

Moving further, on a planetary scale, taking into account indirect land use effect is crucial to avoid underestimating forest emissions, i.e. overestimating the forest sink effect [8]. Additionally, anthropogenic carbon emissions also lead to natural disturbances. However, this effect is not separable from the base line natural disturbances in the National Inventory Reports data. We also note that future climate change is likely to continue impacting the interaction between disturbance agents [20].

In the following countries, biomass loss levels were lower (in absolute value) in IPCC than in SOEF: Austria, Croatia, Cyprus, Denmark, Finland, Latvia, Netherlands, Romania, Slovenia. Countries where biomass loss levels were higher (in absolute value) in IPCC than in SOEF were: Ireland and Italy.

Considering the stark differences of reported loss values (table 3), there is likely an issue with the expansion factors used in equation 2. Further analysis of the reasons for these discrepancies would require a more detailed model benefiting from growing stock level broken down by species and climate zones.

4. Discussion

The discrepancies across the five sources varied greatly from one country to another. It is difficult to identify the reasons for this incoherence as many sources of errors are compounded in national aggregates. More specifically, the variability along tree species composition, age distribution, soil and climatic conditions is lost in the aggregation process. Disaggregating data across these variables would help to find out the reasons for the differences observed.

Fundamentally, the raw measurements on which all estimates are based, are obtained by observing forests on a very small set of areas localized in space and time. The country-wide forest growth rates are but aggressive interpolations made from these ground measurements. Furthermore, these essential plot data obtained from field campaigns are habitually not divulged by the NFIs and kept secret. To expand the spatial and temporal scales, more players would need to open-source and collect these primordial quantifications.

The data harvesting and merging software we introduce in this article can be reused by others. All data conversion steps have been developed in the python programming language. The software should be capable of updating data automatically as new data becomes available. Though future changes in the structure of the input data might require slight adjustments to the code.

Grassi et al. [8] call for the global vegetation modeling community to: "[...] design future models and model experiments to increase their comparability with historical [Green House Gas Inventories] and thus their relevance in the context of the Paris Agreement". We hope the software module we produced can provide an overview of the biomass losses and gains at national levels and can facilitate comparison attempts by the vegetation and carbon cycle modeling community in the future. The harmonized data assembled here is not sufficient to calibrate a European forest dynamics model, but it provides a series of reference points necessary to validate such a model on historical data. The underlying software demonstrates how to structure the data acquisition and how to implement a conversion algorithm. Can it be a meaningful step towards "the availability and provision of harmonized freely-available databases" [9]?

In the future, the spatial and temporal precision of remote sensing data will continue to increase and maps of biomass change will become available. There will be a pressing need to compare them with ground based observations of biomass losses and gains. At the international level, these comparisons can be supported by a framework for sharing ground based observation. Building such a framework will be very challenging. It will be challenging on the scientific level because each ground data collection is adapted to its own biome and it will be challenging on the policy level because each national forest inventory effort is shape to its particular socio-economic context.

Author Contributions: Conceptualization, Lucas Sinclair and Paul Rougieux; Data curation, Lucas Sinclair and Paul Rougieux; Formal analysis, Lucas Sinclair and Paul Rougieux; Methodology, Paul Rougieux; Software, Lucas Sinclair; Visualization, Lucas Sinclair; Writing – original draft, Lucas Sinclair and Paul Rougieux. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: We would like to thank our colleagues of the JRC biomass team. In particular, Roberto Pilli and Raul Abad Vinas for introducing us to the IPCC inventory submission dataset, Andrea Camia, Valerio Avitabile and Nicolas Robert for comments on an early version of this article and Bernd Eckhardt for sharing his experience concerning NFIs data platforms.

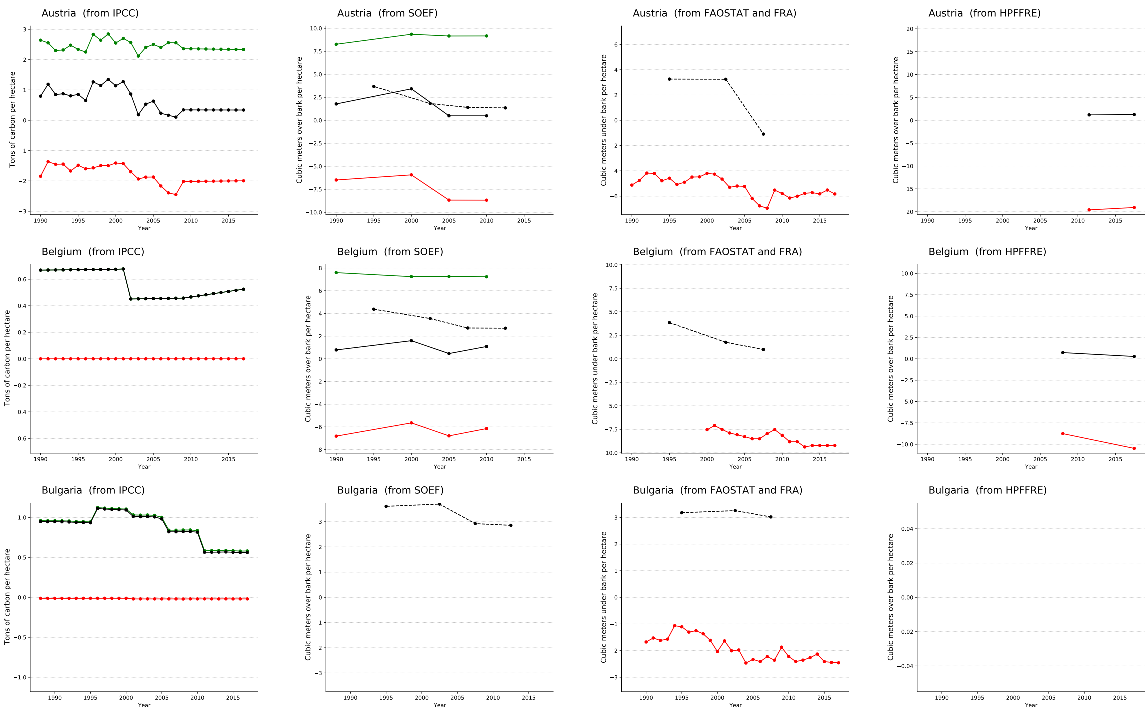
Abbreviations

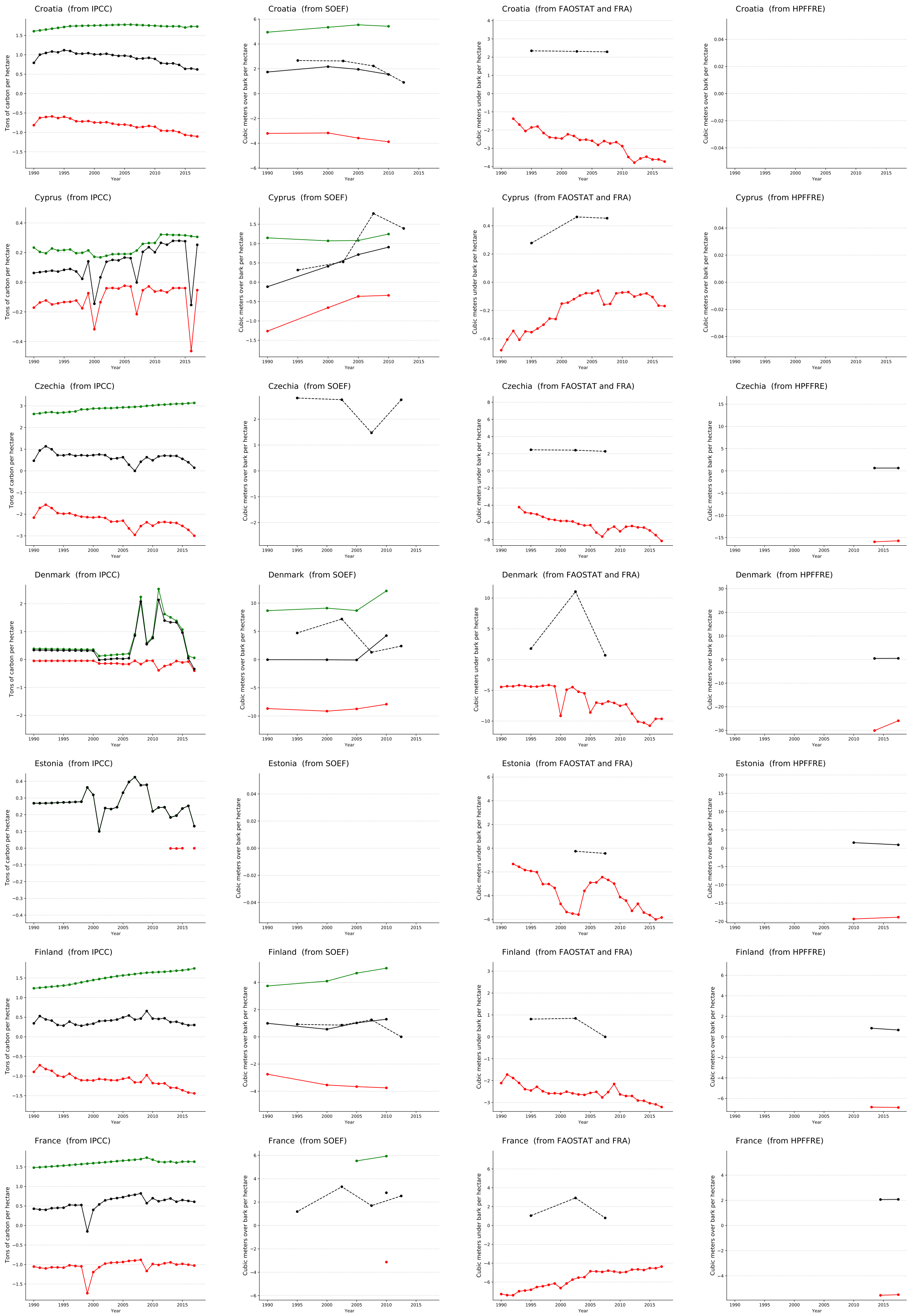
The following abbreviations are used in this manuscript:

API	Application Programming Interface
AWS	Available for wood supply
CRF	Common Reporting Format
CSV	Comma Separated Values format
DDoS	Distributed Denial of Service
EU	European Union
FAOSTAT	Food and Agriculture Organization Statistics
FAWS	Forest available for wood supply
FNAWS	Forest not available for wood supply
FRAWS	Forest available for wood supply with restrictions
GHG	Green House Gas
GUI	Graphical User Interface
HTML	Hypertext markup language
HPFFRE	Harmonized Projections of Future Forest Resources in Europe
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardization Organization
MIT	Massachusetts Institute of Technology
SI	The International System of Units
SOEF	State Of European Forests
XLS	Microsoft Excel Spreadsheet format
ZIP	Compressed file archive format

Table A1. Proportion of area available for wood supply reported by SOEF and HPFFRE.

Country	SOEF AWS	HPFFRE AWS	AWS+FRAWS
AT	86.3%	85.4%	94.3%
BE	98.1%	100.0%	-
BG	57.9%	-	-
CY	23.8%	-	-
CZ	86.3%	95.0%	-
DE	95.3%	95.5%	99.2%
DK	93.5%	96.2%	-
EE	89.3%	77.3%	90.3%
ES	79.9%	94.7%	-
FI	87.6%	79.3%	89.9%
FR	94.3%	76.4%	94.7%
GB	100.0%	100.0%	-
GR	92.1%	-	-
HR	90.5%	-	-
HU	86.0%	96.8%	-
IE	83.8%	83.8%	99.4%
IT	88.4%	93.8%	-
LT	88.3%	87.1%	98.8%
LU	99.3%	-	-
LV	93.9%	97.1%	-
NL	80.1%	-	-
PL	87.3%	-	-
PT	65.6%	59.3%	-
RO	67.4%	-	-
SE	70.6%	96.2%	-
SI	91.3%	90.0%	-
SK	92.0%	94.9%	98.0%

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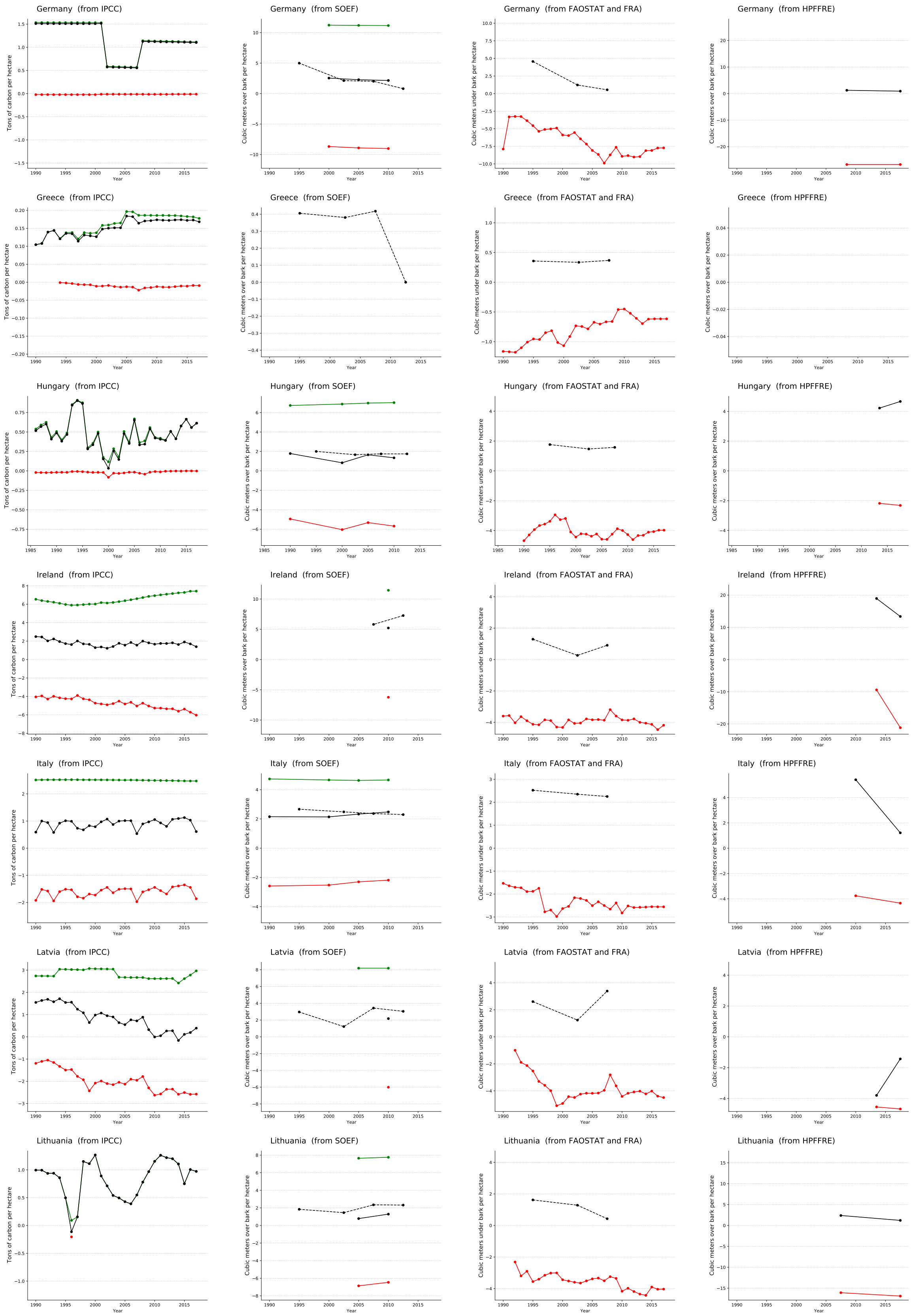
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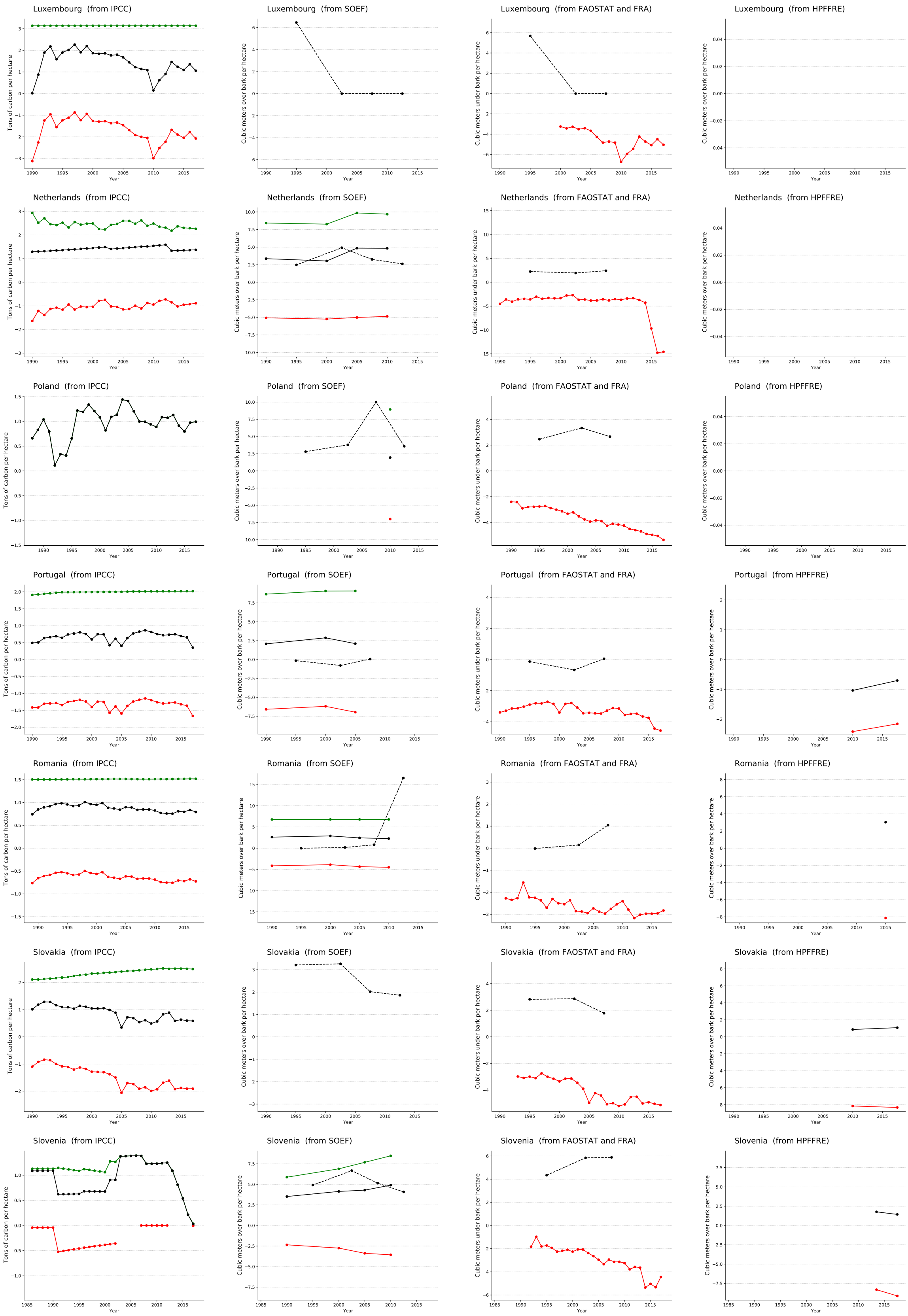
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Cubic meters over bark per hectare
Cubic meters under bark per hectare
Year

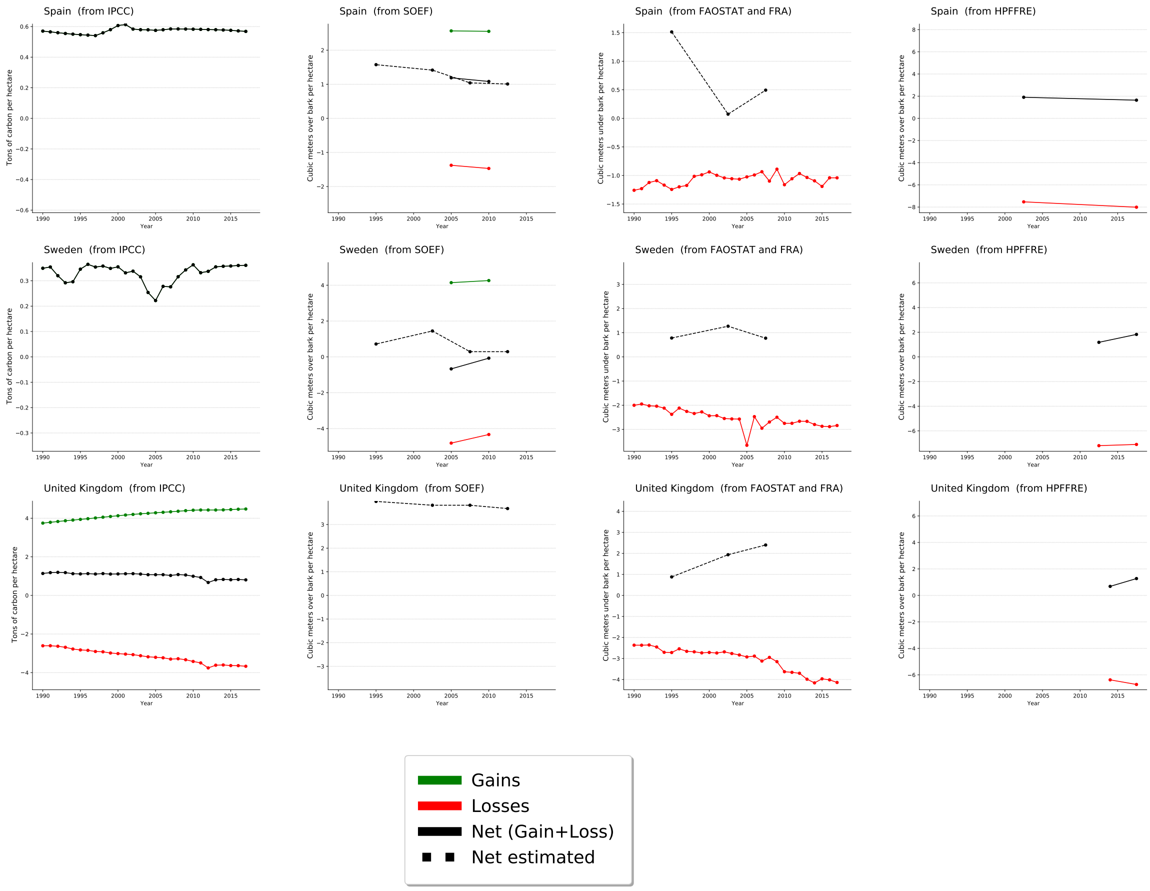
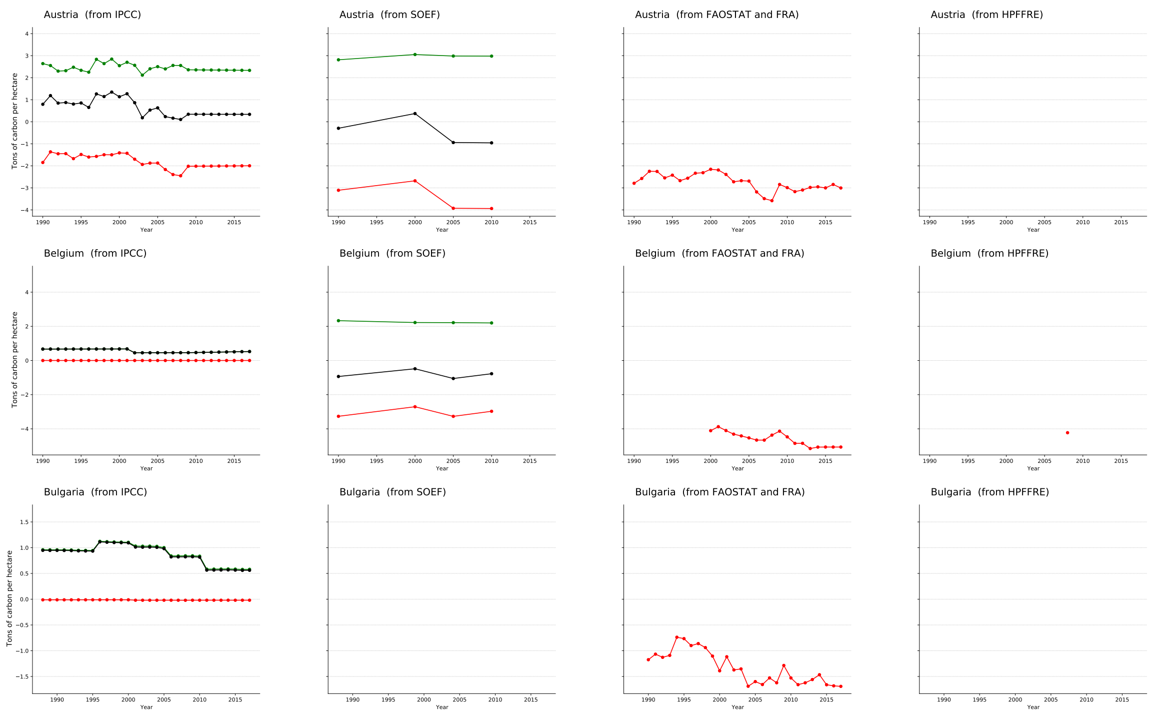
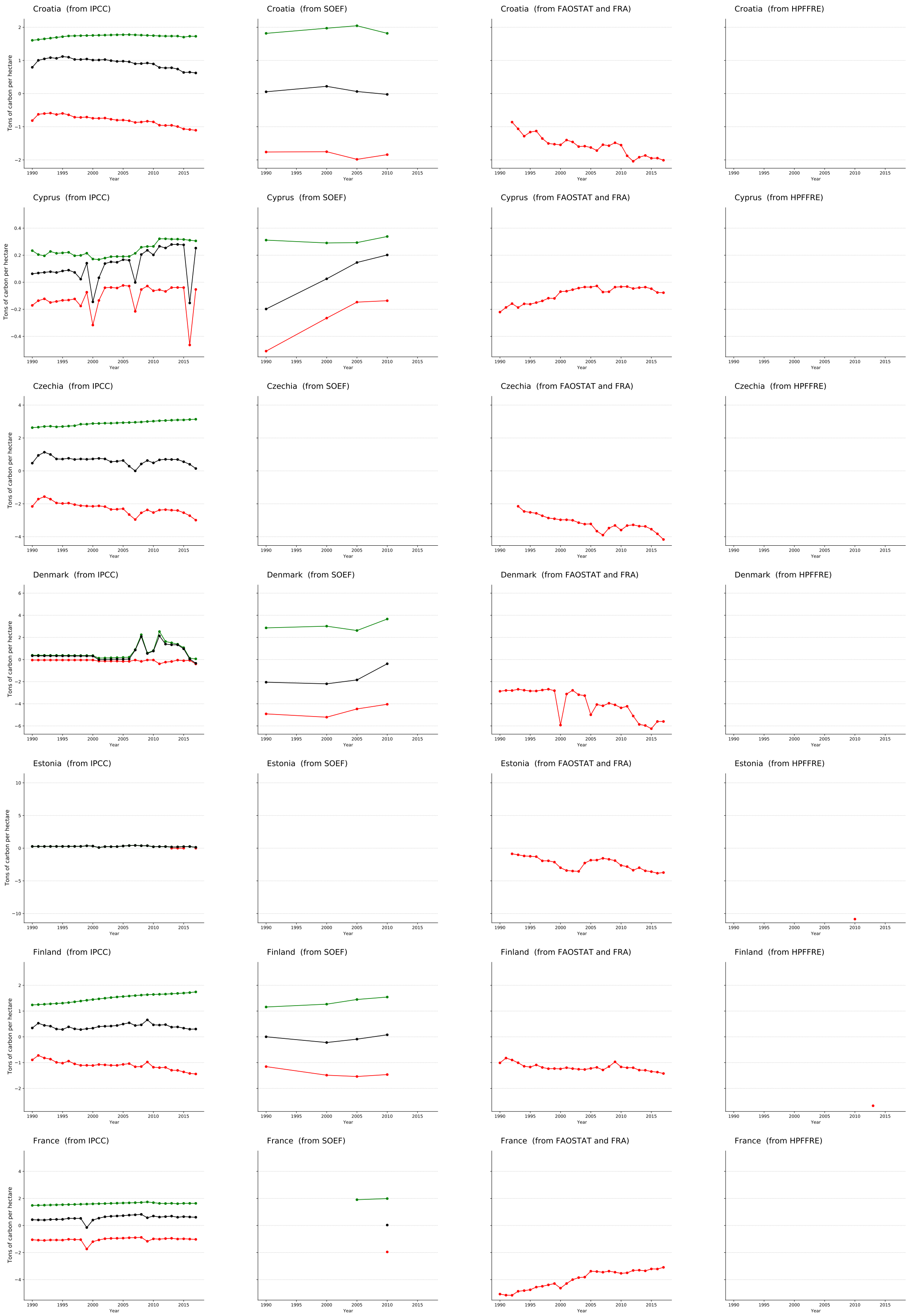


Figure A1. Comparison of the forest dynamics expressed in the original units for all countries.

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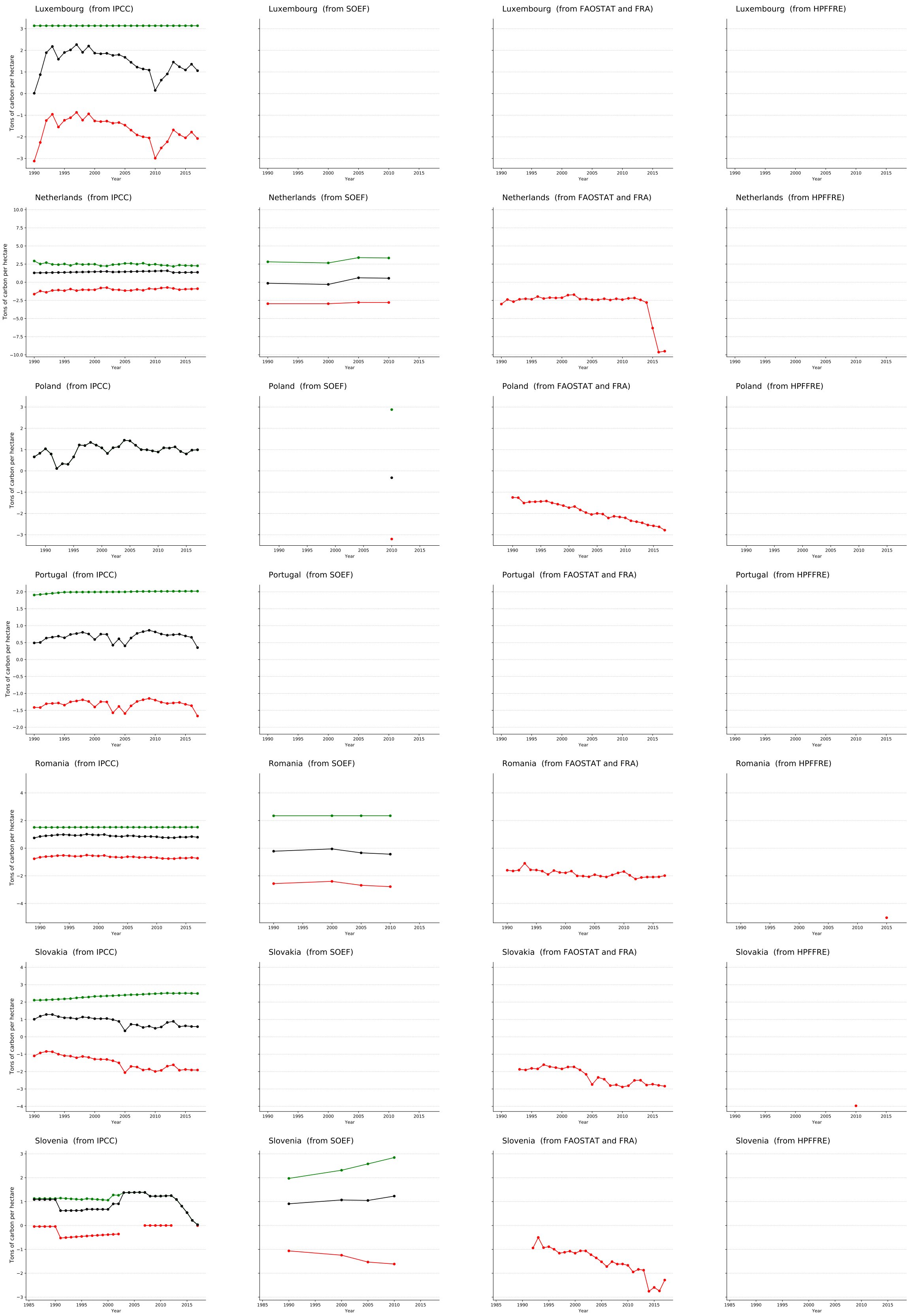
Tons of carbon per hectare
Year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Tons of carbon per hectare
Year

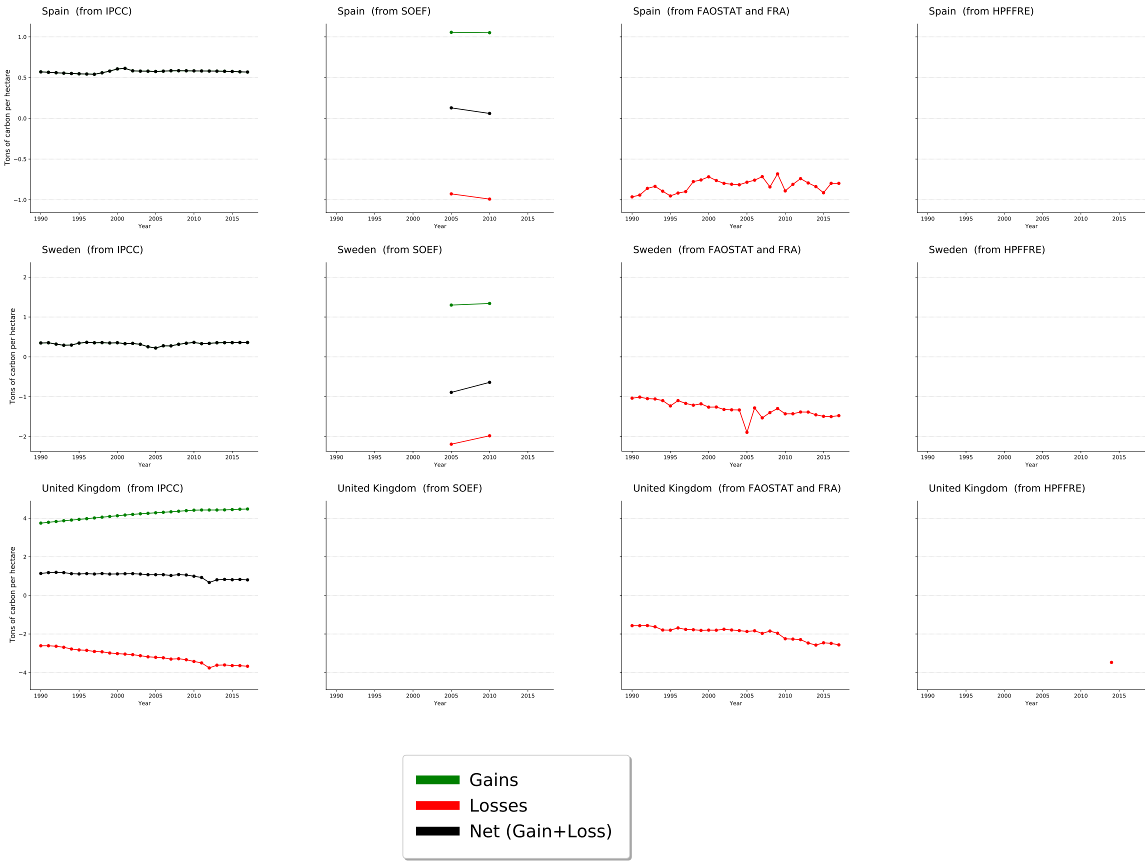

Figure A2. Comparison of the forest dynamics expressed in tonnes of carbon for all countries.

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