

Article

Joining Criteria for Harmonizing European Forest Available for Wood Supply Estimates. Case Studies from National Forest Inventories

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Abstract: For national and international reporting on forest available for wood supply (FAWS), harmonized data are needed. This information is required as forests provide goods for various sectors like the timber industry or the bioenergy sector. The effect of applying different thresholds to the three restriction classes (environmental, social and economic restriction) within the proposed reference definition for FAWS was evaluated. We applied the reference definition for FAWS to national data sets provided by five European National Forest Inventories using harmonized thresholds. The effects on FAWS area and growing stock were evaluated for each restriction and threshold. All countries within this study could report on protected areas. Social restrictions were not applied in any country, data on other restrictions are available but definitions vary. The application of common thresholds for restrictions proved difficult as effects vary between countries. The economic restriction is the most challenging to assess as many countries do not have corresponding data for direct calculation of, e.g., harvesting costs. Using proxies for harvesting costs was difficult, as common thresholds may not be applied in different countries. For standardized reporting, a FAWS definition should be developed that utilizes existing, harmonized indicators to describe restrictions.

Keywords: forest area; wood resources; wood supply; economic; environmental; social; restriction

1. Introduction

National forest inventories (NFIs) are among the most important data providers for national forest resources [1–3]. Nowadays, NFIs are mostly based on statistical sampling [4] providing high quality and interpretable data. Various national and international reporting demands have to be met by NFIs, ranging from vegetation to soil, land use, ecosystem services or biodiversity [5,6]. In the global context, data are needed by the Food and Agriculture Organization of the United Nations (FAO) for the “Global Forest Resource Assessment” (FRA). Within the frame of European reporting, data

are provided for the “State of Europe’s Forests” (SoEF) report [7] compiled by Forest Europe, United Nations Economic Commission for Europe (UNECE), and FAO, among others.

One important prerequisite for international reporting is the existence of well elaborated and applicable definitions for target variables. These definitions set the basis to compare international indicators used in decision making in forest policy and forest management. An extensive summary of existing processes where harmonization is important can be found in [8]. With regards to harmonization, extensive work has been conducted under COST Action E43 “Harmonisation of National Forest Inventories in Europe: Techniques for Common Reporting” of the European program, Cooperation in Science and Technology (COST) [1,2,9,10]. Other studies focus on details and the applicability of common definitions like the forest definition [11–13].

Following [14], forest area can be subdivided into forest available for wood supply (FAWS) and forest not available for wood supply (FNAWS). At national and international levels, FAWS is an important indicator for the actually available wood resource within forests [15]. It is a key target for climate change mitigation and therefore for strategic sectors in Europe, as the increased use of woody biomass is part of the carbon emission reduction scheme of the European Union [16,17]. Additionally, there are large-scale models such as the European Forest Information Scenario model (EFISCEN) [17], which simulate future FAWS resources under assumptions of future wood demand and a given management regime using NFI data as the basis of calculations [15].

As stated in [18], forest related data should be consistent over time. Unfortunately, this is not the case as definitions for key variables change over time [18,19]. This also holds true for the definition of FAWS [18]. A comparison of FAWS estimates over time is thus difficult. Especially as not only definitions change but also NFI methods and personal interpretations of a definition.

Following [14], FAWS is defined as: “Forest where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood. Includes areas where, although there are no such restrictions, harvesting is not taking place, for example areas included in long-term utilization plans or intentions”. Even though [18] encourages not changing existing definitions, we aim to improve the current FAWS definition through recent efforts to harmonize the assessment of FAWS and their estimation at European level. Discussions on possible interpretations of the definition were started within COST action FP1001 COST action FP1001 USEWOOD—Improving data and Information on the Potential Supply of Wood Resources. A European Approach from Multisource National Forest Inventories—followed up on the harmonization work of COST action E43. The main aim was to improve information on the potential sustainable wood supply based on the NFI data. Discussions within COST action FP1001 USEWOOD lead to a new proposed reference definition [15]: Forests where any environmental, social or economic restrictions do not have a significant impact on the current or potential supply of wood. These restrictions can be established by legal rules, managerial/owner decisions or for other reasons.

The proposed reference definition slightly differs from the definition provided by [14] avoiding overlaps between the restriction classes. Additionally, recommendations and clarifications (notes) for their assessment were proposed:

1. Environmental restrictions should consider protected areas, protected habitats or species, and also those protective forests meeting the above requirements. Age or diameter class restriction should not be taken into account (except in the case of protected ancient forest).
2. Social restrictions include restrictions to protect aesthetic, historical, cultural, spiritual, or recreational values as well as areas where the owner has made the decision to cease wood harvesting in order to focus on other goods and services (e.g., leisure, landscape, and aesthetic value).
3. The economic restrictions considered are those affecting the economic value of wood utilization (profitability). These include: Accessibility (such as distance to nearest road), slope and soil condition. Short-term market fluctuations should not be considered.

Once the new, common FAWS definition is established, its application may pose challenging. The interpretation of definitions related to forest that are not necessarily based on scientific evidence, but a result of a policy process is often difficult. At the same time, data availability and national concepts vary between countries. In the case of FAWS, countries have different criteria and thresholds that affect the profitability of harvesting operations or accessibility, which is due to particular characteristics of their forests and their forest management systems. Regarding environmental restrictions, different protection levels are described by countries (harvesting partly restricted, completely restricted or restricted for a particular silvicultural system), at different scales (cuttings can be restricted to a particular tree species) [15]. Since a definition for FAWS has to meet both policy obligations and data availability within reporting countries, we analyzed the consistency of information on FAWS. We included data from five countries (Ireland, Italy, Spain, Sweden and Switzerland) and discussed the consequences of considering the proposed reference definition with different, harmonized restriction thresholds. We show that forest area and growing stock within countries presented is smaller applying the reference definition. Additionally, fixed thresholds reduce the subjectivity introduced by personal interpretations of the definition. Thus, introducing a reference definition for FAWS by applying fixed thresholds could lead to more harmonized FAWS estimates. Further, we suggest using well-defined restrictions, like the International Union for Conservation of Nature (IUCN) classes for protected areas. Harmonization of the economic restriction proved challenging, as countries do not necessarily assess all of the information required to accurately describe economic restrictions (e.g., harvesting cost).

2. Materials and Methods

The five countries included in this study were selected as they vary in size, climatic conditions, topography, and conditions of forest sector. Further, they cover different parts of Europe. Sweden and Ireland are situated in the north, Switzerland in the center, and Spain and Italy are in the south of Europe. Forest cover percent varies between 10.9% in Ireland and 68.4% Sweden. All remaining countries have a forest cover percent between 31.4% and 36.9% [7]. In Ireland, plantations account for 90.6% of the forest area, whereas only 0.1% of the Swiss forest area is planted [7]. Coniferous forests dominate in Ireland and Sweden with 68.6% and 72.0% of cover, respectively, whereas broadleaved forests dominate in Italy and Spain, at 74.4% and 54.9%, respectively. About 25.9% of the forest area in Switzerland is mixed forest and 32.6% are predominantly broadleaved forests [20].

2.1. Data Description

Ireland: Ireland's NFI involved a detailed survey of permanent forest sample plots based on a randomized systematic grid sample design. Plots were established on a 2 km × 2 km grid, which equated to 17,423 plots nationally, each representing approximately 400 ha. Each circular NFI sample plot comprises 500 m², and is permanent in nature to allow future re-sampling as required. An initial desk study was carried out to identify land-use type, including forest areas, at each of the sample points using aerial photos and existing digital maps of forests. The NFI is a periodic inventory and the aim is to reassess plots on a five-year cycle. The first NFI was completed in 2006, the second NFI in 2012 and the third NFI is due for completion in 2017. In Ireland's NFI, availability for wood supply is assessed post field data collection. Information assessed in the field (e.g., slope) is used in the classification of availability for wood supply where forests located on sites steeper than 58% slope are considered FNAWS. Forest productivity is described using qualitative attributes instead of quantitative attributes such as m³ ha⁻¹, e.g., broadleaf forests that have a forest type of scrub are classified as being "unlikely" to be available for wood supply.

Italy: The Italian NFI is a periodic inventory with a cycle of approximately 10 years. The sampling design is a three-phase sampling for stratification [21]. During the second phase field survey, measurements of qualitative attributes are assessed in about 30,000 plots, including availability for wood supply according to the definition in [14]. Availability for wood supply is assessed by the field crews on the basis of a synthetic evaluation, taking into account many aspects concerning site

conditions (accessibility, slope, and distance from forest roads), local timber market conditions and legal restrictions. NFI estimates of quantitative parameters (e.g., growing stock or annual increment) are derived from the third phase on a subsample of the second phase sample, stratified by region and forest category (about 7000 plots in INFC2005) [22].

Spain: The Spanish NFI is a periodic inventory with a 10-year cycle. Permanent sample plots are established at the intersections of a 1 km × 1 km UTM grid [23]. Since the Third Spanish National Forest Inventory (SNFI3), land cover classification and forest area estimation are described prior to the NFI using the National Forest Map (E:1:50,000) (SNFM50). The main dataset used to estimate Spanish FAWS is taken from the permanent plots of the SNFI3 conducted during the Third Spanish National Forest Inventory (NFI3, 1997 and 2007—99,051 plots), which is the latest inventory cycle finished, and the National Forest Map (SNFM50—1:50,000), which is the cartography base of SNFI3. Other data used are the Spanish Digital Terrain Model (25 m × 25 m), the Protected Areas Map (1:50,000) (2013) and the National Erosion Map (1:40,000).

Sweden: The Swedish NFI uses a combination of 2710 temporal and 4290 permanent cluster plots. The cluster size (number of sub-cluster plots) depends on the strata where the cluster is located (geographic location). Each NFI cycle has a duration of five years and a fifth of all cluster plots are assessed in the field each year. Every sub-cluster plot, or part of plot, is assigned to both a national and an international (FAO classes) land-use classification [5]. FAWS is defined as productive forestland outside protected areas.

Switzerland: Within the Swiss NFI, data are collected on about 6600 plots in the field [24]. The Swiss NFI is a continuous inventory with permanent sample plots where one NFI cycle takes nine years and one-ninth of all sample plots are assessed each year. Not all relevant information on forests can be directly assessed on the plot in the field. This includes data on forest planning, ownership, forest functions, time of last silvicultural treatment or applied harvesting technologies, and forest road network. This data are assessed by means of interviews with all Swiss local foresters. The interviews are conducted once every NFI cycle, for all sample plots.

2.2. Description of National Restrictions Estimation

2.2.1. Environmental and Social Restrictions

Ireland: Environmental restrictions rarely exclude forest areas from supplying timber products in Ireland. There are no strict laws in place that prohibit the harvesting of timber.

Landowners that want to fell trees need to obtain a license from the government. During the evaluation process, the likely effect of the harvesting operations on the environment is evaluated. In certain circumstances, the license is referred to a third party to obtain specialist observations on the likely impact of the harvesting operations. In the majority of cases, operational measures are put in place to mitigate against potential damage to the sensitive ecosystems, which allows timber harvesting to proceed.

While measures to mitigate against the negative impacts of harvesting operations on the environment allow timber to be harvested, they do have an impact on future supply. For example, in the past forests were established directly adjacent to watercourses. Nowadays, strict guidelines insist that setback areas are put in place during reforestation.

Social restrictions only have a significant impact on a small number of sites, which are primarily aimed at providing recreation. In these forest areas, harvesting trees is not prohibited but it tends not to be a regular occurrence. These forest areas, designated for recreation, are primarily located in the public forest estate. During NFI, field data collection recreation is noted on the plot.

Italy: Legal restrictions on areas protected for biodiversity and nature conservation can affect availability for wood supply when fellings are totally banned or severely restricted. This happens in very limited areas such as integral nature reserves that represent only a small percentage of protected forests. Boundaries of integral nature reserves and other protected areas are provided as GIS-layers by

the Ministry of Environment, which is responsible for updating them regularly. NFI field crews are provided with this information and with information on local protected areas at the beginning of the field campaign. Other restrictions that can interdict availability for wood supply are those concerning military areas or areas close to roads or power lines, among others.

Social restrictions are very rare. Only small forest areas that are classified as integral reserves by the management plan, for any social or environmental reason, could be considered. This possibility is limited to very specific circumstances and local situations. Data on the presence and extent of these cases are to some extent lacking or difficult to assess.

Spain: In Spain, three main environmental restrictions could be considered: protected areas, protected species and protective forest against erosion.

Protected areas that pose a limitation for wood supply include strict reserves and national parks. The protected areas map was overlaid with the national forest map using GIS to estimate the restricted area. Regional laws define the protected species for which logging is not allowed. Only forest areas where these protected species are dominant have been excluded from FAWS.

The main environmental restriction in Spain regarding protective forest is erosion. The maximum threshold of annual erosion considered by the Ministry of Agriculture, Food and Environment is $50 \text{ t} \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$. The correspondent restriction area has been estimated using the National Forest Map and the National Erosion Map.

Sweden: In Sweden, all productive forestland, with a potential site productivity $\geq 1 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ is considered FAWS, however excluding: (1) forest reserves; (2) habitat protection; (3) protection agreements; (4) zones of environmental concerns in regeneration felling; and (5) voluntarily protected forests. Exclusions 1–4 are all legal restrictions. Voluntarily protected forests (Exclusion 5), on the other hand, could be considered as a social restriction, except for certification schemes where usually at least 5% of the forest area should be set aside by the owner. Swedish forest owners voluntarily protect approximately two million hectares of productive forestland. The Swedish NFI can estimate the total productive forest area and the area of forest reserves using GIS-layers provided by the Swedish National Environmental Protection Agency. Swedish FAWS is then estimated using NFI data and registered data from the Swedish Forest Agency on voluntarily protected areas.

Switzerland: In Switzerland, data on environmental and social functions are not taken into account when estimating FAWS, except for strictly protected areas. All forest accessible by foot, excluding forest reserves, are classified FAWS. The perimeters of forest reserves are known and are excluded using GIS. Nevertheless, other data would be available and could be used for FAWS estimates as it is assessed by means of interviews with local foresters. Each sample plot may have several special forest functions that can be valid, e.g., “drinking water protection”, “wood production”, “recreation” and “protective function” [25]. Out of the special forest functions, there is one primary forest function for each sample plot. The primary forest function is defined by planning documents like the forest development plan (WEP) or by expert opinion from the forest service.

With regards to social restrictions, data are also collected through interviews with local foresters. In addition to the (special) forest function, which could be “recreation”, data describing the actual recreational use are assessed. Estimates on the intensity and seasonality of recreational use are given by the local foresters or models on potential recreation demand [24,25]. In addition, the main types of recreational use, e.g., “biking” or “hiking”, are assessed.

2.2.2. Economic Restrictions

Ireland: In Ireland, economic restrictions are taken into account by forest owners when assessing the feasibility of harvesting a forest area. The public forest estate managers assess the profitability of undertaking harvesting operations during a planning phase. This assessment takes into consideration the distance to market, harvesting cost and the likely return from the harvested products. The NFI does not take into consideration the economic considerations when assessing availability of wood for

supply. In the absence of local information about the products potentially available or the distance to markets, it is felt that such an assessment is too subjective for field assessment in Ireland.

Italy: The economic profitability of wood utilization is considered by the NFI crews when classifying availability for wood supply. On the basis of timber quality (round wood, fuel wood, *etc.*), harvesting methods and local market condition, the field crews decide whether there is some economic interest to fell trees in that area. However, no calculation of harvesting costs is done.

Spain: In Spain, FNAWS due to economic restrictions can only be approximated through site condition indicators as slope. Nationally, Spain applies a slope threshold of 50% with the exception of the Cantabrian range, where a threshold of 80% is applied

Sweden: Due to the applied definition of “productive forestland”, Sweden automatically has a legal and economical restriction, as cutting is illegal on “non-productive forestland”. Otherwise, no other economic restrictions are applied.

Switzerland: Switzerland is one of three European countries calculating harvesting costs at plot level. One problem for a wide application within Europe is the lack appropriate models describing harvesting costs. One such model is the HeProMo model [26], which is applied in the Swiss NFI. In addition to the models, data from field plots and interviews with local foresters are required for the calculation. The data from field plots deliver information on stand variables like growing stock, obstacles for harvesting operations or slope, whereas the interviews give information on applied harvesting technologies for each sample plot as well as on the forest road network. Combining both information sources realistic harvesting costs can be calculated.

2.3. Proposed International Thresholds and Data Analysis

As only few countries are able to calculate harvesting costs, we propose introducing factors that have large influence on harvesting costs as proxies (Table 1). The proxies from Table 1 are widely available for NFIs and thus well suited for application in different countries under differing conditions. The proxies were derived by national experts from several countries. In this paper, average annual productivity has been considered instead of wood quality due to data availability and its direct relation to profitability of the forest.

Table 1. Thresholds applied for the estimation of FAWS (Forest Available for Wood Supply) area applying the economic restriction of the FAWS definition [15].

Restrictions	Thresholds		
	Units	Minimum	Maximum
Slope	%	35	140
Distance from road	m	400	2000
Average annual productivity	m ³ ·ha ⁻¹ ·year ⁻¹	1	3

NFI plot data and information from auxiliary sources were used to estimate FAWS and FNAWS area as well as corresponding growing stocks applying common restrictions for all restriction types of the FAWS definition. Environmental and social restrictions include natural protected areas, protected species, and protective forests, whereas the economic restriction includes slope, distance to the nearest road, and average annual productivity.

NFI data from Italy, Spain, and Switzerland were analyzed to provide further insights on the influence of the restrictions. For Italy, the chi-square test was used to test for the difference between FAWS and FNAWS (frequency data and independent samples) in relation to different types of restrictions. Spanish NFI data were used to estimate overlaps between different FNAWS areas of each restriction using GIS, where the aim was to determine the interdependence of restrictions and to analyze the relevance of their inclusion for FAWS assessment. For Switzerland, the relationship

between percent slope on the plot and the time of the last silvicultural treatment and between slope and harvesting costs have been described and tested using the Wilcoxon test for paired samples.

3. Results

3.1. Environmental and Social Restrictions

The most common restriction affecting forest areas is related to natural protected areas (Table 2). In relation to the total forest area, Italy and Sweden have the largest protected forest area with 35% and 12%, respectively. Taking Ireland and Switzerland into account, one can observe that growing stock per ha is lower in natural protected areas, compared to the total forest area. In Ireland, it is $238 \text{ m}^3 \cdot \text{ha}^{-1}$ and, in Switzerland, it is $191 \text{ m}^3 \cdot \text{ha}^{-1}$. Similarly in Italy, there is a trend of lower growing stock in natural protected areas compared to other forest ($141.9 \text{ m}^3 \cdot \text{ha}^{-1}$ instead of $144.9 \text{ m}^3 \cdot \text{ha}^{-1}$). However, for most important forest types in Italy, the opposite is true: coniferous, broadleaved and mixed forests show higher growing stocks per hectare in protected areas (279.8 , 132.1 and $196.5 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively) than in unprotected areas (260.4 , 107.5 and $176.6 \text{ m}^3 \cdot \text{ha}^{-1}$, respectively); the lower average growing stock of protected forest is due to approximately 600,000 ha of sclerophyllous vegetation, transitional woodland and shrubs that are included in protected areas.

Table 2. Percentages affected by environmental and social restrictions of availability for wood supply, for the five European countries of the case study are given.

Country	Natural Protected Areas		Protected Species		Protective Forests		Total	
	FA	GS	FA	GS	FA	GS	TFA	TGS
Italy	34.97	34.25	-	-	87.38	89.76	8759	1,269,416
Ireland	0.68	1.22	-	-	-	-	732	97,476
Spain	0.77	1.54	0.02	0.04	9.37	8.01	18,173	913,540
Sweden	11.76	9.53	-	-	-	-	27,124	3,276,361
Switzerland	0.34	0.19	-	-	49.66	50.14	1184	409,914

“FA” is forest area (%) and “GS” is growing stock (%). “TFA” is the total forest area within a country (1000 ha) and “TGS” is the total growing stock (1000 m^3).

Protected species are only considered in Spain where species such as *Juniperus thurifera* L. can be dominant in a forest, leading to the protection of the stand. This occurs on 0.02% of the total forest area.

Protective forests are managed in different ways. There are forests where interventions should not be significant and others where silvicultural management is needed. Protective forests cover about 50.0% of the total forest area in Switzerland (see Table 2). These forests mostly have the function of protecting against rock fall, processes in channels or avalanches and water protection. Silvicultural management is mandatory in these forests to maintain their stability and protective function. As a more bespoke type of forest management is needed, wood supply is not free of constraints. Nevertheless, protective forest area is considered FAWS in Switzerland. The main function in many Spanish forests is the protection against soil erosion, desertification, and regulation of the hydrological cycle. Erosion has been considered a key restriction occurring in 9.4% of the total forest area. In Ireland, no formal designations for protective forests exist. While some forests are managed primarily to protect aquatic ecosystems, there are no data sources available to quantify this. Overall, the area of protective forests is very small in Ireland. In Italy, about 87.0% of forests are classified as protective forests (protecting soil and water) and are managed under some kind of constraint. Nevertheless, protective forests are generally considered FAWS, provided that no other restriction exists, as harvesting is usually not forbidden in these forests.

Historical, cultural and spiritual as well as ownership protected areas are not of relevance in any country within this study.

3.2. Economic Restrictions

Table 3 shows forest area and growing stock estimates obtained applying the thresholds proposed in Table 1. Slope as measured on the plot is assessed in most NFIs, as it is easy to measure and needed for the calculation of sample plot size on sloped terrain. From the countries within this study, only Spain and Ireland consider slope as a restriction for FAWS. Applying the national threshold, 7.1% of the total forest area in Spain is not available for wood supply. In Switzerland, all forest that is not accessible by foot, e.g., it is too steep, is considered FNAWS. Thus, slope can be considered as an indirect restriction. Comparing the relative forest area affected by the minimum threshold for slope shows that between 23.0% and 96.1% of total forest area remains FAWS. The application of the maximum threshold of 140% slope shows that not all countries have forests occurring on very steep slopes. Thus, figures are only reported for Italy, Spain, and Switzerland. Using the maximum threshold, 9.6%, 0.2% and 0.03% of total forest area would be FNAWS in Italy, Switzerland and Spain, respectively.

Distance to next road is not considered as a restriction within any of the countries of this study. Italy, Sweden, and Switzerland were able to report on distance to road as restriction. Comparing the forest where the forest plots have less than 400 m distance to the next forest road, Switzerland has 67.9% of forest in this condition. In Italy and Sweden, it would be 50.5% and 60.7%, respectively. Applying the maximum threshold of 2000 m, 96.8% of forest area is located closer than 2000 m to the next forest road in Switzerland. In Italy and Sweden, it would be 69.3% and 81.5%, respectively. When looking at the growing stock, 72.4% would still be available in Switzerland, applying the minimum threshold for distance to the next road. In Italy, 50.1% of the total growing stock, and in Sweden 70.2% of growing stock would be available. Applying a distance of 2000 m to the next forest road as restriction leads to 98.3% of available growing stock in Switzerland, 69.0% in Italy, and 90.7% in Sweden.

Average annual productivity is considered within the Swedish definition for FAWS. Further, only Sweden and Switzerland were able to report on average annual productivity. Applying the minimum threshold (Table 1), which is the same as the Swedish national threshold leads to 82.5% and 91.6% forest area and growing stock for Sweden, which is above the threshold. In Switzerland, 96.5% of total forest area and 97.1% of total growing stock remain available, whereas the application of the maximum threshold leads to 63.6% available forest area in Sweden, and 88.4% in Switzerland. The effect on growing stock is smaller than for forest area. Here, 77.0% of total growing stock remains available in Sweden, and 90.0% in Switzerland.

Table 3. Forest available for wood supply.

Country		Slope			Distance to Road			Average Annual Productivity		
		Min	Max	National	Min	Max	National	Min	Max	National
Italy	Forest area	36.20	90.36	-	50.52	69.31	-	-	-	-
	Growing stock	32.88	95.43	-	50.08	69.01	-	-	-	-
Ireland	Forest area	96.17	NA	100.00	-	-	-	-	-	-
	Growing stock	95.07	NA	100.00	-	-	-	-	-	-
Spain	Forest area	77.03	99.97	92.89	-	-	-	-	-	-
	Growing stock	62.08	99.96	88.70	-	-	-	-	-	-
Sweden	Forest area	81.32	NA	-	60.68	81.53	-	17.50	36.39	17.50
	Growing stock	89.68	NA	-	70.15	90.74	-	8.38	22.06	8.38
Switzerland	Forest area	34.46	99.83	-	67.91	96.79	-	3.55	11.57	-
	Growing stock	37.27	99.89	-	72.35	98.27	-	2.90	9.06	-

Forest area (%) and growing stock (%) of national total estimated by applying the thresholds proposed to assess the economic restriction for European countries. Figures for minimum (Min), maximum (Max), and National thresholds refer to the percentage that is below the defined threshold. "NA" means that this threshold is not applicable (e.g., forest area slope in country is not steep enough), whereas "-" means that no data is available.

3.3. Case Study Italy: FAWS and FNAWS in Relation to Restrictions

For Italy, the distribution of NFI plots in relation to restrictions affecting availability for wood supply are shown in Figure 1. Compared with FAWS, FNAWS is characterized by a significantly higher proportion of natural protected areas and areas not accessible to NFI crews (chi-square p -value <0.001). Similarly, the distribution of NFI plots by percent slope class and distance to forest road class differs significantly between FAWS and FNAWS (chi-square p -value <0.001). A large proportion of plots are located in slope classes (60%–80% and $>80\%$) and a smaller proportion in slope classes (0%–20% and 20%–40%). Similarly, the proportion of FNAWS is larger where the distance from the forest to the forest road is greater (Figure 1d). As no information on the main restriction for each plot was collected during the survey, it is not possible to know the causes determining the judgment of non-availability for wood supply given by the NFI crews.

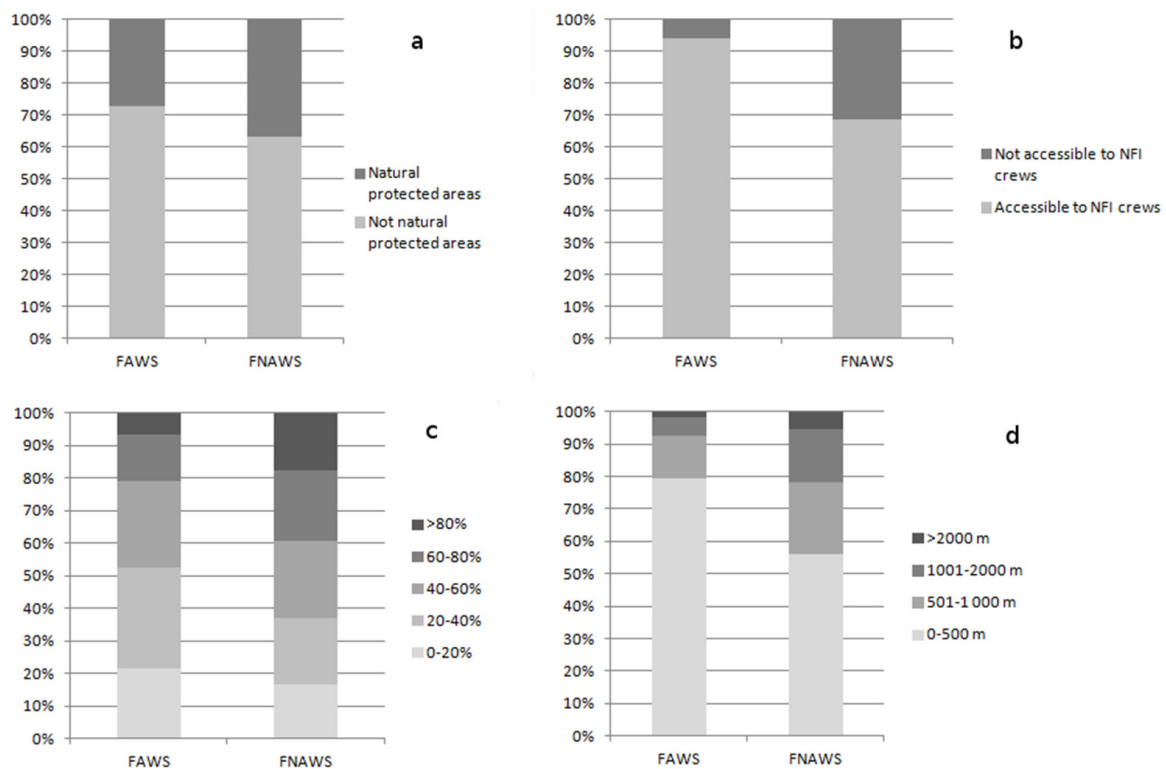


Figure 1. Distribution of forest plots by: protection status (a); accessibility to NFI crews (b); percent slope (c); and distance to forest roads (d). FAWS: forest available for wood supply; FNAWS: forest not available for wood supply.

3.4. Case Study Sapin: Spatial Overlaps of Restrictions

The interaction of forest areas available for wood supply were analyzed for individual restrictions by evaluating the spatial overlaps among the restricted areas (Table 4). It is remarkable that the restrictions “protected areas” and “protected species” do not overlap, whereas overlaps occur between restrictions “slope”, “protected species”, and “protected areas”.

Table 4. Overlapping forest areas (1000 ha) of forest not available for wood supply in Spain, applying different restrictions.

	Min Slope (35%)	Max Slope (140%)	Protected Areas	Protected Species	Protective Forest (Soil)
Min slope	4174.68	6.10	65.59	1.88	447.27
Max slope		6.10	0.77	0.00	0.45
Protected areas			139.53	0.00	9.90
Protected species				3.09	0.48
Protective forest (soil)					1713.78

3.5. Case Study Switzerland: Using Slope as Restriction for FAWS

For Switzerland, the relationship between the slope on the plot and the time of last silvicultural treatment was investigated. Using the two-sample Wilcoxon test, a significant relationship (p -value < 0.01) was shown and silvicultural treatments mostly occurred within the last 50 years. The time between silvicultural treatments is longer for forests on steeper the slopes, where the difference is no longer significant at slopes over 70%.

Further, the relationship between harvesting costs (Swiss Francs (CHF)) and slope was analyzed. We were able to show that harvesting costs are higher if the slope is high. When testing for differences among harvesting cost classes 1–6 (Figure 2), the two-sample Wilcoxon test shows that classes 1, 2, 3, and 4 significantly differ (p -value < 0.001) from each other, whereas classes 4, 5 and 6 do not significantly differ from each other, meaning that at a slope of about 65%, which is the median slope of harvesting cost class 4, harvesting costs do not significantly increase further.

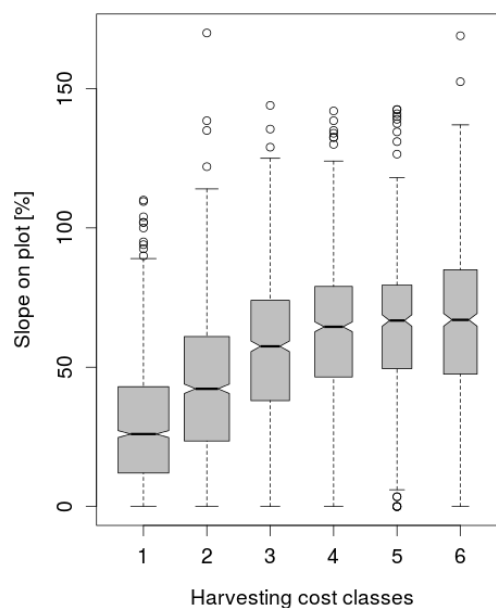


Figure 2. Slope dependent harvesting costs for Switzerland. Harvesting cost classes correspond to: (1) till 50 CHF/m³; (2) 51–75 CHF/m³; (3) 76–100 CHF/m³; (4) 101–125 CHF/m³; (5) 126–150 CHF/m³; and (6) >150 CHF/m³. Width of boxes corresponds to sample size in each class, not overlapping notches can indicate significant differences between classes.

4. Discussion

Looking at the national data from Italy, it is apparent that predictions of FAWS and FNAWS are not possible using just one single predictor. Various factors need to be considered simultaneously. Moreover, the classification of availability for wood supply does not seem feasible using automatic or

semi-automatic classification procedures (e.g., overlapping GIS-layers or using specific algorithms). Complementary information (sometimes even subjective judgment) is needed to determine the possible causes affecting availability for wood supply. Nevertheless, the method applied in the second Italian NFI could be improved to reduce subjectivity, for example by dividing different types of FNAWS by type of restriction (environmental, social, legal, economic, and others).

The analysis of the overlaps between the FNAWS restriction areas carried out in Spain showed that percentages of overlaps are low and therefore it is not possible to exclude any of the restrictions. Although the proportion FNAWS due to protected species is small, it is nevertheless an important legal restriction at regional level, and it does not overlap with protected areas.

4.1. Environmental and Social Restrictions

For the environmental restrictions, the exclusion of natural protected areas such as national parks is most commonly applied or possible to apply (Table 5). Using internationally defined categories such as the IUCN categories allows for standardized reporting of protected areas, even though [27] suggest that the interpretation of IUCN classes can vary. We observed that the total size of protected areas differs among countries and that growing stocks are generally lower within protected areas, compared to the remaining forest areas. This shows that in some countries protected areas are located on less productive sites or include special forest types that are less stocked, which was also reported by [28].

Table 5. Summary table of the environmental, social and economic restrictions within each country.

Country	Restriction		
	Environmental	Social	Economic
Ireland	Evaluation of impact of harvesting operation on the environment. Areas near water courses.	Recreation forests.	Profitability of harvesting operation (not taken into account by NFI).
Italy	Protected areas (e.g., reserves for nature conservation).	Very rare and special case due to management plan.	Profitability of harvesting operation.
Spain	Protected areas (e.g., reserves for nature conservation). Protected species. Protective forest against soil erosion.	-	Regionalized slope threshold.
Sweden	Site productivity. Protected areas (e.g., reserves for nature conservation). Habitat protection. Protection agreements. Zones of environmental concerns in regeneration felling	Voluntarily protected forests	Site productivity
Switzerland	Protected areas (e.g., reserves for nature conservation).	-	-

All countries where protective functions exist are able to report respective forest areas and corresponding growing stock. Nevertheless, the protective function can be manifold and defined differently within each country, leading to a less harmonized area estimate compared to protected areas defined by IUCN classes (for a detailed description of the IUCN classes, see [29]). In addition, the total exclusion of protective forests from FAWS can lead to incorrect interpretations. In Switzerland, about 50% of the forest area is covered by protective forests, and these forests are available for wood supply. Protective forests need specific management to maintain their protective function, including

harvesting of trees. The exclusion of protective forests from FAWS would be misleading for Switzerland. We would suggest excluding protective forests from FAWS that are also excluded on a national level (national definition for FAWS). Specific guidelines could be developed specifying the restrictions needed to exclude protective forests from FAWS.

Apart from protective functions, no environmental and social restrictions were mentioned among those applied to assess FNAWS. Recreational forests, as mentioned in the reference definition, are either not assessed as such during NFI sampling or are considered as FAWS (Table 5). In Switzerland, where forest functions are assessed, forests with the primary forest function “recreation” are FAWS and harvesting does take place. Following [30], forests have to meet a wide range of demands and silvicultural management can have a positive effect on recreational value [31,32].

All other restrictions were either not of importance at national level or only applied within one country. Protected species only play a role in Spain and ownership only in Sweden. Historical, cultural and spiritual areas were not reported for any country.

Thus, it can be concluded that among the different restrictions, natural protected areas are the most commonly applied to assess availability for wood supply, and the related information can be readily harmonized.

4.2. Economic Restrictions

Economic considerations are often the basis for harvesting operations. Unless there is an over-riding management obligation (e.g., maintaining the protective function of a forest), harvesting operations will most likely not be carried out under uneconomic conditions. Keeping this in mind, the economic restriction of the definition on FAWS was further elaborated.

The most common restriction affecting economic profitability of harvesting is slope, which is commonly measured within NFIs. One drawback for using slope as a restriction is the strong correlation with topography of a specific country. This was shown by applying the minimum threshold for slope, resulting in 23% to 96% of the total forest area remaining FAWS within respective countries. Slope is applied as a national restriction in Spain (in legislation) and Ireland (only within the NFI), assuming that erosion would be too strong or harvesting is not feasible or uneconomic at steeper slopes.

An analysis of Swiss NFI data has shown that most silvicultural treatments occurred within the last 50 years, irrespective of the slope, even though a trend towards larger intervals between treatments is apparent on steeper slopes. Considering this result, further analysis was conducted towards the correlation between slope and harvesting costs. Harvesting costs are among the most important factors to consider for economic feasibility. Here, we showed that at a slope of about 65%, harvesting costs do not increase further. This led to the conclusion that considering slope above 65% for an economic restriction threshold might not be useful. Nevertheless, a suitable threshold for harmonized reporting could be defined using the strong relationship between slopes and harvesting costs. In Switzerland, approximations to a certain slope could be done by taking the mean timber price in Switzerland for the most common tree species, which is currently within the range of 100 CHF [33]. With this, the profitability of harvesting operations seems to decline at a slope of 66%, corresponding to harvesting cost class 4 and above.

The distance to the nearest road also has a large influence on harvesting costs [34,35]. Three of the five participating countries were able to report on the distance to the nearest road. Thus, it can be assumed that not all countries would be able to report on this restriction on a European level. In addition, as for slope, the density of road networks is influenced by various factors, such as topography, harvesting system or ownership, among others.

Using the average annual growth rate as a restriction is common practice in northern Europe. Sweden applies a threshold of $1 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{year}^{-1}$ average annual productivity for defining productive forests. Harvesting operations are not allowed within unproductive forests. Applying productivity as a threshold could deliver comparable results and would reflect an economic restriction, as rotation periods on unproductive sites are longer.

5. Conclusions

The geographic distribution of the countries included in this study and extent of the forest area therein, provided a robust basis to evaluate the concept of availability of wood supply in European forests. However, further studies should be done in other European countries to broaden our understanding of the concept across Europe. The diversity of factors that distinguish national forest areas poses a challenge for the harmonized estimation of FAWS, e.g. environmental conditions such as slope. For international reporting, the focus should be on well-defined restrictions, like the IUCN classes for protected areas. All countries within this study could report on these classes. Social restrictions were not applied and likely play a minor role in Europe. For other restrictions, such as protective forests, information is mostly available but definitions can vary. In addition, forests with protective functions can be considered as FAWS at a national level, but clear guidance for reporting should be developed. Economic restrictions are applied, but not all countries are able to report on them. Our analysis did not provide a clear threshold to apply for the economic restriction. There may be a possibility to establish an international threshold for slope or site productivity. Here, further research will be conducted.

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Abbreviations

The following abbreviations are used in this manuscript:

FA:	Forest area
FAO:	Food and Agriculture Organization of the United Nations
FAWS:	Forest Available for Wood Supply
FNAWS:	Forest Not Available for Wood Supply
FRA:	Forest Resource Assessment
GR:	Growing Stock
IUCN:	International Union for Conservation of Nature
NAFIDAS:	National Forest Inventory Data Analysing System
NFI:	National Forest Inventory
SNFI3:	Third Spanish National Forest Inventory
SNFM50:	Spanish National Forest Map 1:50,000
SoEF:	State of Europe's Forests
TFA:	Total Forest area
TGR:	Total Growing Stock
UNECE:	United Nations Economic Commission for Europe
WEP:	Forest Development Plan

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