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Linking forest policy issues and decision support tools in Europe

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ABSTRACT

While very many decision-support (DS) tools (i.e. models and decision support systems (DSS)) have been developed to address forest management problems in Europe, the use of such tools in supporting forest policy processes remains limited. Additionally, while there has been very limited sharing of these tools between European countries, there may be an untapped potential for both users and developers in this area.

This paper focuses on improving understanding and capacities in the use of forest DS tools for decision making by identifying major forest policy areas, tools available to support them, compatibility of existing tools with the requirements of forest policy areas, potential areas where tools may be shared between countries and factors limiting the use of DS tools in forest policy.

Data collection was based on expert interviews. The questionnaire, which comprised a combination of open- and close-ended questions, was forwarded to experts via email. Expert interviews were completed via Skype with the input of one policy specialist and one modeller/decision support specialist from each country.

This study categorised key forest policy areas and the DS tools available to support them. Almost one third of these forest policy areas were not addressed by any DS tool. The analysis also revealed that DS tools are mainly developed to assist scientists and policy decision makers to address smaller spatial scales, that they are more orientated to single decision makers with a predominant focus on market wood products. In addition, through an attribute-matching exercise, the DS tools that could potentially be used in other countries to support similar forest policy areas were also identified.

Interviews highlighted some of the reasons why DS tools are seldom used in policy making processes; these include a lack of trust in the actual use of the tools as well as a perception of inadequacy for the specifics of real policy process. This research provides a detailed overview of existing DS tools and the forest policy areas that they address. It further provides information on how to address or reduce the gap between DS tools functionalities and requirements from policy makers.

1. Introduction

Decision making can be defined as a process of identifying and choosing alternatives based on the analysis of a problem taking into account the values and preferences of the decision makers involved. It occurs in various parts of the policy cycle (e.g. agenda setting, formulation, adoption, implementation, evaluation). How policy issues are brought onto the political agenda already involves various forms of

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decision making as some issues are considered while others not. Shedding light on *how* forest decision making takes place in policy making processes and how this can influence the implementation of forest policies is an important field of scientific research (Lovrić et al., 2018; Geitzenauer et al., 2017; Leipold, 2017; Sotirov et al., 2017). Decision support systems and forest policy analysis research can both be used to learn about decision making processes but from very different perspectives.

Forest policy analysis, a sub-discipline of forest sciences, aims to analyse actors' and institutions' roles in decision-making and implementation processes as well as to examine the development and importance of their related interests, resources, rules and ideas (actors' beliefs, frames, narratives and discourses) (eg. Arts, 2012) that result in forest policy change or stasis. Forest policy analysis sheds light on how and by whom forest-related policy issues are brought onto the agenda and what actors (alone or in coalitions) participate or fail to participate in decision-making and implementation processes (e.g. Sotirov and Winkel, 2016; Krott, 2005). It analyses what interests and beliefs those actors hold (e.g. Maryudi and Sahide, 2017), and also how these interests and beliefs are formed and framed by bigger discourses embedded in wider society (Arts et al., 2010; Pülzl et al., 2014). Finally, insights into constraints or supports in terms of rules and norms that guide policy institutions are gathered through this form of analysis. What forest policy analysts study less is the actual way decisions are formed during the process. This could be due to the fact that scientists rarely form part of the decision-making processes and therefore lack the opportunity to thoroughly observe them. Additionally, scientists are not often granted the opportunity to interview politicians and it is often difficult to access information about the background to political deals. Although interviews or the analysis of survey data help shed light on the questions relating to how and by whom decisions are made, they might not be fully able to access information on the actual way decisions are made. Furthermore, forest policy scientists are usually more interested in the role of interests and beliefs that actors hold, into what arguments grounded in larger societal discourses are used and into the norms and rules that guide this behaviour than in uncovering the precise way the decision was made (e.g. Fiore et al., 2007).

The use of computerised systems to address decision making, namely in the framework of forest resource management planning has expanded substantially over the past decades (Borges et al., 2014). The integrated functionality of spatial and non-spatial data resources, forest models and operations research techniques within DS tools has contributed to increasing the efficiency and effectiveness of forest management planning (e.g. Reynolds et al., 2008). It has been further reported that DS tools can provide information and insights to support forest policy analysis research (e.g. Menzel et al., 2012).

Rose et al. (1993) described a pioneering approach to use a DSS to address policy making in the framework of the development of the Minnesota Generic Environmental Impact Statement (GEIS) (Jaakko Poyry Consulting, 1994). This study was developed in response to a petition by Minnesota citizens for the State Environmental Quality Board (EQB) to evaluate the cumulative impacts of timber harvesting and forest management in Minnesota. It involved over 60 scientists and represents one of the most extensive studies of timber harvesting and forest resources ever conducted in the United States (Kilgore, 1992). It contributed to the development of the State Sustainable Forest Resources Act in 1995 (Kilgore and Ek, 2007). The DSS encompassed a management information system, a module with forest models and a prescription writer as well as an innovative Lagrangean relaxation technique (Rose et al., 1993).

Nabuurs and Paivinen (1996) reviewed early models and systems used to support large-scale forest scenario analysis. Reynolds et al. (2005) also summarised opportunities for continued systems' development to support forest management and policy analysis, namely through the enhancement of group decision making, participatory planning, multiple ownership integration within the process of developing sustainable forest management policy initiatives. These opportunities were recently further highlighted by the use of DS tools to support policy analysis and policy backcasting processes in the framework of the EU Integral project (http://www.integral-project.eu/). The potential of DS tools to address policy issues was demonstrated in several case studies across Europe (e.g. Borges et al., 2017; Corrigan and Nieuwenhuis, 2016; Cintas et al., 2016; Eggers et al., 2015; Lämås et al., 2015; Orazio et al., 2017). Nevertheless, these studies did not develop a systematic approach to match DS tools to policy areas and issues they may better address.

To understand what relevant forest policy issues can be identified on national political agendas and how these might be related to forest policy making and DS tools, this article takes its starting point from the recently issued State of Europe's Forests report, (Europe and Unece, 2015) which is structured according to six criteria and 35 quantitative and 12 qualitative indicators of Sustainable Forest Management (SFM). The report provides a comparative overview of what economic (economic value of goods and ecosystem services, contribution to the national GDPs etc.), environmental (forest regeneration, biological diversity protection, fight against climate change and forest damage) and social benefits forests provide in Europe and Russia as well as the challenges that arise in this context. Since within the framework of FOREST EUROPE sustainable forest management practices and principles for national forest programmes have been defined, those were also deemed relevant for national agendas as member countries have to report on their implementation. Additionally, the EU Forest Strategy (EC, 2013) and the EU rural development policy provide guiding principles and potential co-funding for forests nationally (Pülzl and Wydra, 2014). In this context, priority topics important for member states' national forest policies are: improving rural areas, using bioenergy from woody biomass, addressing climate change, protecting forests and enhancing ecosystem services. The Natura 2000 legislation, the FLEGT initiative and the Timber Regulation are also highly relevant in terms of forest protection and preventing illegal logging within and beyond the EU. Finally, additional forest policy issues also arise in the national context and are related to national forest legislation. In this regard, forest ownership, restrictions for forest management and forest management planning, as well as forest road development and infrastructure to access forests, play a crucial role. So there is broad variation of forest policy issues in Europe that determine the forest policy agenda at national level. To facilitate data collection and analysis, this study uses the term ‘forest policy area’ (FPA), which is an ensemble of specific forest policy issues that are placed high on the forest policy agenda in a country.

The main objective of this article is to improve the understanding of the potential of DS tools to enhance decision making processes. To achieve this, four distinct steps were undertaken. First, we identify the major forest policy issues in European countries and the availability of DS tools to support forest policy decision making; second, we assess how the problem domains of existing DS tools matched with current FPAs; third, we identify the DS tools that may address similar FPAs in other countries and fourth, we consider the factors limiting the use of DS tools in forest policy areas. To our knowledge, no research to date has focussed on systematically assessing the use and the potential use of DS tools to support decision-making processes in specific forest policy areas (FPAs).

2. Material and methods

2.1. Data collection

The research has been conducted in the context of the EU COST Action “Orchestrating forest-related policy analysis in Europe” (ORCHESTRA). It involved the design of a questionnaire which comprised a combination of open- and close-ended questions to capture the capacity of DS tools for decision making. Open-ended questions facilitated

capturing relevant policies, country-specific issues and information about available DS tools. With the close-ended questions respondents were asked to express their opinion relative to a predefined set of descriptors.

The questionnaire was structured as follows:

1. Background information: to collect basic data about the respondents (country, institution, age, and educational background).
2. 'Warm up' questions: to elicit information on the expertise of respondents (i.e. level of involvement in forest policy processes during the last five years, level of personal knowledge of forest policy processes and DS tools).
3. Identification of FPAs: to identify and describe the most important FPAs in national forest policy processes during the last five years (including the classification of the FPAs according to the set of dimensions and attributes defined in Eriksson and Borges (2014), see below). (Note: to facilitate the analysis, FPAs that address similar problems were later classified into groups called 'Forest Policy Topics' (FPTs)).
4. Identification and use of DS tools: to identify DS tools used in specific FPAs and to classify these tools according to the predefined set of dimensions and attributes of FPAs.
5. Reasons that inhibit use: to collect opinions on why DS tools are not more routinely used in forest policy processes.

As the data collection was based on expert interviews, the participation of at least one policy specialist and one DS tool specialist from each country was deemed essential. To ensure consistency in the level of detail and the interpretation of questions, all questionnaires were completed in conjunction with both experts and a representative of ORCHESTRA via Skype calls (the duration of these calls ranged from 40 min to 2 h). The Skype calls also provided an opportunity for the interviewees to add any additional information that they felt was important. The responses that were recorded during the calls were subsequently forwarded to the interviewees so they could validate the information and correct any errors or inconsistencies.

In total, 30 experts, mostly ORCHESTRA COST Action participants, were interviewed in this study. Some countries, in total 8, were represented by one expert, who had knowledge in both fields (policy and DS tools). They represented 19 European countries[1]: Lithuania (LTU), Estonia (EST), Russia (RUS), Ireland (IRL), the UK (GBR*), Spain (ESP*), Austria (AUT), Turkey (TUR), Czech Republic (CZE*), Germany (DEU), Romania (ROU*), France (FRA*), Italy (ITA), Slovakia (SVK*), Sweden (SWE), Bosnia-Herzegovina (BIH), Finland (FIN*), Portugal (PRT) and Bulgaria (BGR*).

Most of the interviewees were directly (9) or indirectly (17) involved in forest policy processes. The respondents identified their knowledge of FPAs in their country as either average (14) or expert (16); in all countries except one a DS tools' specialists with average (9) or expert (11) DSS developer's knowledge were interviewed. Most (25) interviewees work in a scientific institution, two work in a Ministry of Environment or Natural Resources, two are employed in both institutions (Ministry of Environment and a scientific institution) and one is working in a forest agency.

2.1.1. Methodological note on data collection and analysis

2.1.1.1. Identification of forest policy areas and the principle applied in creating 'forest policy topic' groupings. A mixed methods approach that included a questionnaire and interviews as a remedy, to data collection was chosen in an effort to capture the full spectrum of FPAs that could potentially exist across all countries surveyed; the data analysis was conducted by screening the questionnaires and clustering the FPAs. In order to classify all FPAs to FPTs, interviewees were asked to link their identified FPAs with the FPTs described by Dobšinská et al. (2015). Ultimately, in an effort to create discrete and unambiguous FPTs, some of those described in Dobšinská et al. (2015) were further subdivided to create additional groupings. Based on key words and concepts used in the FPAs, the 95 identified FPAs were classified into 16 FPT groups.

2.1.1.2. Identification of DS tools. When some respondents reported on more than five DS tools, they were asked to name the five most important DS tools. The analysis was conducted on the first five DS tools that were presented and classified according to the set of dimensions and attributes. The DS tools identified were classified into four main groups: decision support systems (DSS), simulators (SM), growth models (GM) and national forest service and inventory systems (NFS). A DSS was defined as a model-based software system that contains four components: (i) a language system (LS) that enables users to communicate with and use the DSS (ii) a presentation system (PS) for displaying outputs (iii) a knowledge system (KS) for storing the input information and (iv) a problem processing system (PPS) (Burstein and Holsapple, 2008). To distinguish between growth models (GM) and simulators (SM), this study applied the approach presented in Pretzsch et al. (2002) who defined a growth model as a set of equations that defines only tree competition and tree growth whereas a simulator is defined as a system that includes the implementation of these equations as a computer programme with the input and output routines as well as the possibility to interactively influence a simulation run. Finally, national forest service systems are computer-based tools focusing on regional/local problems supporting the management of national or government forests and are mainly dedicated to storing and processing data using databases.

2.1.1.3. DS tools usage in forest policy processes. Respondents were asked to identify which DS tools, if any, were used during forest policy decision-making phases in relation to each of the five most important FPAs. Three forest policy decision-making phases were defined: (i) policy formulation (which relates to definition of strategies, identification and evaluation of impediments, development of tactical plans), (ii) policy implementation (which relates to actions for implementing strategic and tactical plans), and (iii) policy evaluation (which relates to policy effectiveness, resources and means to maintain success, and processes for remediating failures).

2.1.1.4. Comparing FPAs by analysing their dimensions. The relation between FPAs and DS tools was analysed by linking them through dimensions and attributes. The dimensions relate to different aspects of FPAs (i.e. target group, temporal and spatial scale, modes of decision-making, goods and services, purpose of policy instrument) whereas attributes relate to different forms that these dimensions may take (see Table 1). The list of dimensions used was initially the one presented in Eriksson and Borges (2014); however, since that list was developed to analyse forest ecosystem management planning problems, the dimension "purposes of the policy" was included to facilitate a thorough analysis of FPA dimensions. Additionally, the dimension "temporal scale" was only applied to the analysis of DS tools as it could have different implications in the analysis of FPAs (e.g. policy making might focus only on short to medium term aspects due to the strong influence of periodic elections).

2.2. Data analysis

2.2.1. The data analysis was conducted in four steps

The first step in comparing FPAs' dimensions was to identify how many FPAs are represented by specific dimensions and attributes; it was then possible to calculate the percentage of FPAs that represent individual attributes. The percentage of DS tools that address individual

[1] The acronyms of countries are based on ISO 3166–1 alpha-3 standard. They are used hereafter in the text.
*Indicates countries, in which only one expert was interviewed.

Table 1
Dimension and attributes used to define FPAs (adapted from Eriksson and Borges (2014)).

Dimensions	*Attributes*
Policy target groups	○ Forest owners ○ Wood industry ○ Scientists, NGOs ○ Policy decision makers
Temporal scale	○ Short-term (up to 2 years) ○ Medium-term (2 to 10 years) ○ Long-term (> 10 years)
Spatial scale	○ International ○ National ○ Regional ○ Local/Community level ○ Forest/Landscape level ○ Stand level ○ Single tree level
Decision makers	○ Participatory decision making (involving multiple stakeholders) ○ More than one decision maker (involving only one stakeholder) ○ One decision maker
Goods and services addressed	○ Market non-wood products (fruits, cork, mushrooms, medicine) ○ Market wood products (round wood, pulpwood, biomass) ○ Market services (recreation, hunting, fishing…) ○ Non market services public goods, aesthetic values, water, biodiversity…)
Purposes of the policy instrument	○ Informational ○ Regulatory ○ Economic

attributes was calculated in the same way. The dimensions that do not overlap for FPAs and DS tools i.e. “purpose of the policy” and “temporal scale” were excluded from the analysis.

The second step of the analysis focussed on the “not addressed” attributes. For each FPA, any attributes that were not addressed by any DS tool were identified from the output of step one. While questionnaire respondents were not required to rank the FPAs in perceived order of importance, the FPAs were listed from one to five. By implementing a Spearman's rank correlation analysis (see Zar, 2013), it was possible to analyse if there is a relationship between the order of FPAs and the number of “not addressed” attributes. Furthermore, the results from all countries were amalgamated and the total number of FPAs with attributes “not addressed” by any DS tool was calculated.

In step three, the number of FPA attributes that were not addressed by any DS tool was counted per country. All countries were categorised into one of five groups according to the number of DS tools available, i.e. whether they had 5, 4, 3, 2 or 1 DS tool(s). To find out if there were any statistical differences between the numbers of “not addressed” attributes in predefined groups, the Kruskal-Wallis nonparametric test for multiple independent samples (Zar, 2013) was used. Initially, it was used to compare countries with 5 and 4 DS tools; then group 3 was added; then groups 2 and 1 were added. A significant difference was reported if the Kruskal-Wallis p value was ≤ 0.05 (analysis conducted using ‘Statistica 10’).

An attempt was made to identify whether existing DS tools could potentially be used to address FPAs in other countries. Given that FPAs were classified into FPTs and the DS tools were linked to FPAs, it was possible to assign the various DS tools to FPTs. Thus for each FPT, a table of FPAs and supporting DS tools was constructed. Next, the attributes of each FPA were compared with the attributes of the DS tools irrespective of the country of origin. Then, for all DS tools available in the FPT group, the number of “not addressed” attributes was calculated. The DS tool with the least number of “not addressed” attributes may potentially be adapted for use in other countries. It is important to point out that this study did not evaluate any other properties of the DS tools like ecological constraints of the species considered, validity of equations or general language barriers.

The final step in the analysis was to identify the main reasons that inhibit the use of DS tools in forest policy processes. For this purpose the section of the questionnaire with open-ended questions was used; the responses received were classified into 10 groups based on keywords and a collaborative discussion among the authors.

3. Results

3.1. Identification of Forest policy areas

The largest grouping of FPAs (13 in total) relates to the activation of the market economy, low profitability and added value of forests, potential wood supply and non-wood forest products. These FPAs were relevant in countries all across Europe (e.g. ESP, PRT, AUT, CZE, SVK, FIN, TUR). Ten FPAs related to financial support or compensation for forest owners, nature conservation restrictions and property rights of forest owners versus social interests. Lack of cooperation among non-industrial private forest owners was seen as an important issue in several countries (LTU, SVK, ROU, DEU, SWE, PRT). Many of the Baltic States, and SVK, highlighted eight FPAs related to bureaucratic restrictions of forest management. In western European countries (e.g. FRA, DEU, AUT), seven FPAs related to climate change adaptation and mitigation. The responses from FRA and ITA highlighted the importance of a low carbon economy and the need for estimations of potential carbon fixation. In countries like RUS, BIH, FIN, BGR and SWE, 7 FPAs highlighted the need for advances in legislation, forest strategies, and the establishment of national forest programs. Afforestation of agricultural land, deep peat restocking, responses to ash dieback and transformation of conifer plantations to natural broadleaved stands (in total 6 FPAs) were issues mentioned by respondents from CZE, GBR and BGR. In eastern and southern European countries (e.g. ITA, RUS, ROU, SVK), 6 FPAs dealing with multifunctional landscape planning, developing national forest inventory systems, technical standards and less state-regulated forest management planning were identified. Only four countries (FRA, GBR, BiH, and ESP) identified FPAs explicitly related to sustainable forest management. FPAs related to biodiversity conservation in forestry were mainly relevant in FRA, DEU, AUT and SWE. FPAs related to the use of wood for energy production were mentioned in EST, DEU, FIN and ITA. In DEU, ITA, FIN and SWE, FPAs concerning the use of wood for renewable energy and development of strategies for bioenergy were highlighted. FPAs relating to illegal cuttings (ROU, BIH and ITA) as well as forest fires (ESP, PRT, TUR and RUS) were more or less specific for southern European countries. FPAs related to restrictions on forestry arising from Natura 2000, ecosystem services, rural development, land use policy and forest roads and infrastructure were mentioned by very few countries. The full list of FPAs is presented in Appendix A.

3.2. Identification of DS tools

In total, respondents identified 24 decision support systems (DSS), 14 simulators (SM), 6 growth models (GM) and 9 tools used by National Forest Services (NFS) to support different FPAs (Table 2).

The analysis revealed that 30 FPAs were not addressed by any of the existing DS tools (Appendix A). Four countries (LTU, AUT, FRA and FIN) reported one FPA and ROU reported two FPAs that are not addressed by any DS tool. Five countries (RUS, IRL, CZE, ITA and SWE) reported three FPAs which were not addressed by any DS tool. The highest number of FPAs (4 and 5 respectively) not addressed by DS tools were found in TUR and BiH.

Table 2
DS tools that are currently used to support decision-making processes in FPAs in different European countries.

DS tools	Country (FPA#)	DS tools	Country (FPA#)
Decision support systems			
MONTE	ESP (1, 2, 3, 4, 5)	DSD	AUT (3)
FFSM	FRA (1,2)	RODAL	ESP (3)
WEBBASE service	FIN (3,4)	PINEA2	ESP(3,5)
iFORIS-iNET	IRL (1,4)	SADFLOR	PRT (1)
EFESE	FRA (5)	CONES	AUT (4)
Ecological site classification	GRB (1,5)	EFISCEN	BGR (2)
MELA	FIN (1,2)	PROGETTOBOSCO	ITA (4)
SIMFLOR	PRT (1,3)	ETÇAP	TUR (3)
Recharge.green biomasfor	ITA (2)	SUMAL	ROU (1)
Heureka	SWE (1,2)	MULTICRITERIAL DMM	ROU (4)
CLIMCHALP	AUT (3)	Forest management planning system based on FOX PRO and GIS	ROU (5)
AFM tool box	AUT (3)	DEA	LTU (1,4)
Simulators			
SILVA	DEU (1,2,3,4,5)	GESMO	ESP (3)
BWINPRO	DEU (1, 3,4,5)	FOREST GALES	GRB (4)
WALDPLANNER	DEU (1, 3,4,5)	ECOSYSTEM SERVICE ASSESSMENT	GRB (2)
WEHAM	DEU (1, 3,4,5)	Establishment and management information system	GRB (3)
WILDFIRE BEHAVIOUR SIMULATORS	PRT (3)	EASYFORCLIM	FRA (3)
SIMANFOR	ESP (1)	PICUS	AUT (2,3,5)
ESCEN	ESP (1)	KUPOLIS	LTU (2,5)
Models			
MARGOT	FRA (1,2)	Forest growth models	RUS(3)
ALADINCLIMATE	CZE (1)	Growth and yield models	PRT(1)
Forest growth models	EST (1,2)	GIS based models	RUS (5)
Formulas and procedures	EST (5)	National account system of logging	BGR (1,2,5)
National forest service systems			
National data bank of forest stands	BGR (1,2,3,4,5)	National forestry register data base	EST (3,4)
National account system of forest area	BGR (1,2,3,4,5)	National forest inventory model	CZE (3)
National account system of silviculture activities	BGR (1,2,5)	Forest management plans	CZE (3)
ISDW	AUT (4)		

3.3. DS tool usage in forest policy processes

The analysis showed that where DS tools are used in forest policy processes, they are most often employed in the policy formulation phase (70% for the definition of strategies, 57% for the identification and evaluation of impediments and 55% for development of tactical plans). The use of DS tools for forest policy evaluation is also relatively high (53% for reviewing policy effectiveness, 34% for resources and means to maintain success and 45% in processes for remediating failures) whereas they are less often employed during forest policy implementation (49% for negotiations, 13% for regulations, 17% for legislation and 22% for enforcement).

3.4. FPA dimensions and DS tools functionality

FPAs and DS tools were compared by linking them to the dimensions and attributes presented in Table 1. This assessment facilitated the identification of which attributes the FPA affected and how the DS tools addressed the following dimensions: policy target group, spatial scale, mode of decision-making (participatory or not) as well as goods and services (Fig. 1).

Forest owners and policy decision makers clearly stand out as the most common policy target groups affected by FPAs. However, there is a marked difference in the availability of DS tools which address this dimension and forest owners' issues are notably less well attended to than policy decision makers. This pattern is even more pronounced for NGOs despite the fact that their role in decision making and policy implementation is becoming increasingly important. In contrast, the share of DS tools used to address scientists is larger than the share of FPAs that involve scientists; this is relatively unremarkable given that the development of many DS tools originate from scientific research work. In relation to spatial scales, DS tools currently available better address smaller scales (i.e. regional, landscape and stand level) whereas

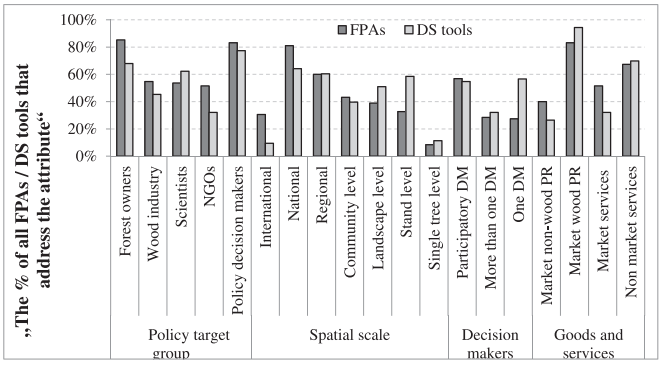

Fig. 1. Comparison of the share of FPAs that are characterized by certain attributes describing the FPAs and the share of DS tools that address these attributes.
(DM = decision-making; PR = products).

the focus of most forest policy developments are either national or regional in nature. Increasingly, there is a focus on participatory planning in relation to decision making in policy development and this is reflected in both the high number of FPAs that focus on this issue and the high level of DS tool availability that address the inclusion of a number of actors. The data also revealed that while DS tools are often constructed for one decision maker, a relatively low number of FPAs are deemed to be targeted at a single decision maker. Finally, from a goods and services perspective, marketed wood and non-marketed services are prominent in regards to both FPAs and DS tools. The evidence presented confirms the importance of DS tools for marketed wood however there is an obvious gap for marketed non-wood products and marketed services; both of which are deemed important from a policy perspective according to the FPAs.

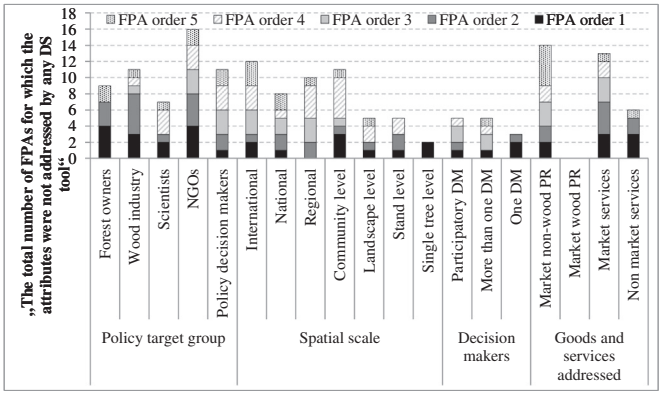

Fig. 2. Comparison of FPAs' addressed and DS tools' supported attributes on a country level.
The bars indicate the total number of FPAs for which attributes were not supported by any DS tool. Order 1 (etc.) relates to the original order of FPAs as presented in the questionnaire responses.

The analysis of the "not addressed" attributes (listed in Appendix B) on a country level revealed that a relationship existed between the order of presented FPAs and the number of "not addressed" attributes (Spearman's rank correlation coefficient of −0.9). It shows that FPAs with the higher number of "not addressed" dimensions were listed first and this also implies that the order in which FPAs' were listed in the questionnaire merits further analysis.

There were 16 FPAs for which the "NGOs" attribute was not addressed by any DS tool (Fig. 2). Of these, 8 FPAs were presented in first and second order in the questionnaires. Similarly, there were 9 and 11 FPAs for which the attributes "Forest owners" and "Wood industry" were not addressed by any DS tool. These not addressed FPAs were ranked in first and second order in the questionnaires. There were 7 FPAs for which the attribute "Scientists" and 11 for which the attribute "Policy decision makers" were not addressed by any DS tool; for both, only 3 were presented in first and second order in the questionnaires.

Fig. 2 also shows that in relation to spatial scale, the attributes "Regional", "Landscape level", "Stand level", and "Single tree level" are much better addressed by DS tools than "International", "National" or "Community level", which can be partly explained by the spatial scope limitations of the existing DS tools.

In relation to decision making, there is a significant amount of DS tools developed to address "One decision maker" in comparison to either "Participatory decision-making" or "More than one decision maker". However, even more marked differences were found when analysing the attributes associated with the "Goods and services" dimension. There were 14 FPAs for which the attribute "Market non-wood products" were not addressed by any DS tool. There were 13 FPAs for which the attribute "Market services" were not addressed. Interestingly, there were no FPAs for which the attribute "Market wood products" was not addressed by DS tools.

It can thus be concluded that DS tools are still mainly developed to assist scientists and policy decision makers, that they support smaller spatial scales, are more orientated to one decision maker, and are very much related to market wood products.

An analysis of the number of FPA attributes that were not addressed by any DS tool based on the number of DS tools available in the country revealed that there was no significant difference in the numbers of "not addressed" attributes between groups of countries with 5 and 4 DS tools. Joining the groups 2, 3, 4 and 5 did not reveal any statistically significant differences. Only when group 1 was added, did the K−W test show significant differences between groups of not addressed dimensions (significance level 0.05) (Fig. 3).

Based on these findings, it can be concluded that one DS tool per country to address FPAs is not sufficient and that a significant reduction

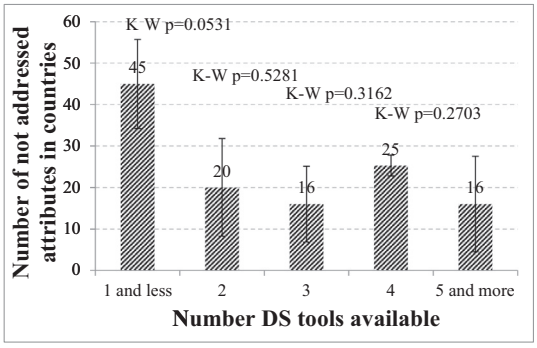

Fig. 3. The relationship between DS tools per country and the mean number of "not addressed" FPAs. (The column shows the mean value for the group, and the error bars indicate the standard deviation).

of "not addressed" attributes is achieved when at least two DS tools are available. However, the availability of a large number (i.e. 5 and more) of DS tools does not lead to further significant reductions in "not addressed attributes".

3.5. Grouping of Forest policy areas into forest policy topics

To facilitate a better understanding of the main topics of concern in relation to forest policy, the FPAs were categorised into 'Forest Policy Topics' (FPTs). In total, 16 FPTs were formulated (descriptions of FPTs and their associated FPAs are listed in Appendix A). The number of FPAs that comprised each FPT varied greatly; for example the FPT "Forest economics" was comprised of 14 FPAs and the FPT "Forest roads and infrastructure" consisted of only three FPAs. This grouping exercise revealed that forest economics, forest ownership and national forest programmes and strategies rank much higher (in terms of nominations by the respondents) than, for example, forest fires, Natura 2000 constraints or ecosystem services.

3.6. Factors limiting the use of DS tools in forest policy making

This study also aimed to identify the factors that potentially limit the use of DS tools in forest policy decision-making processes. In total, 10 factors were listed by the respondents (Table 3) and a comparative analysis showed that the same factors were identified in several countries while some were quite specific to certain countries. One of the main issues identified was the users' lack of confidence in utilising models/DS tools effectively; this was reported in 10 countries. So, even with the existence of many DS tools, potential users do not feel they have sufficient knowledge to use them and, furthermore, do not feel confident in using or interpreting the results.

The complexity of DS tools was highlighted in seven countries and the message here was that DS tools are primarily designed by and for scientists and, that due to their complexity, they are generally considered not suitable for use in policy processes.

Political problems that require immediate decisions and actions are, out of necessity, addressed in a manner that precludes detailed planning and therefore prohibits the development of an appropriate DS tool. On occasion, problems remain unresolved due to bureaucratic barriers or long-standing management traditions.

Experts also highlighted the fact that forest policy issues often arise much faster than DS tools can be developed to address them. Experts from five different countries also pointed out that the results obtained by the application of a DS tool depend on the adequate representation of objectives and preferences of stakeholders. Stakeholders may not fully trust the output of DS tools unless they have a full understanding of the development process. Borges et al. (2014) emphasised the importance of involving the stakeholders in all stages of the DS tools

Table 3
Factors limiting the use of DS tools in forest policy making.

Factors	Countries										
Lack of confidence in users	GBR	AUT	BIH	FIN	PRT	ESP	SVK	IRL	DEU	ROU	ITA
DS tools are primarily designed for scientists; not designed for policy processes in general; too complex.	SWE	RUS	ESP	TUR	ITA	AUT	FIN				
Bureaucratic barriers or management traditions	LTU	TUR	DEU	ROU	ITA	PRT					
Reactive problem solving of politicians; time needed to develop DS tools	SVK	IRL	LTU	EST	ROU	FRA					
The risk that the DS tools' output could be in contrast to what the stakeholder wants	AUT	SWE	DEU	FRA	FIN						
Shortage of applied research due to lack of funding or lack of researchers	LTU	PRT	IRL	DEU	BGR						
Difficulties in gathering appropriate levels of the data for models	GBR	TUR	CZE								
Limitations in current DS tools to produce answers to certain questions	AUT	FRA	FIN								
Intellectual property restrictions	RUS	GBR									
Models are not yet standard tools in forest-related policy as much as they are in forest management/forest science	DEU										

development, namely through appropriate information systems architectures (Marques et al., 2011; Marques et al., 2013).

Although this would facilitate stakeholders' understanding of how solutions are proposed, this approach would require a significant level of input from them and this may not be achievable in all instances.

Additionally, some experts pointed out that there are very many questions that currently can not be answered with DS tools and that further model development is needed. For example, the effect of forest management on many forest ecosystem service dimensions cannot currently be accurately predicted; this limits the usefulness of DS tools in these areas.

Other reasons mentioned in relation to the limited use of DS tools were a “shortage of applied research due to lack of funding”, “difficulties in getting proper data”, and “intellectual property restrictions”. These, however, are issues that are more technical in nature and could potentially be solved quite easily. Finally, experts from Germany pointed out that “the models are not yet standard tools in forest-related policy as much as they are in forest management or forest science”.

In summary, a large number of constraints were identified; some could be resolved from a technical viewpoint, but trust in the use of the DS tools as well as the lack of adequacy for the specific policy processes are concrete barriers for increasing their usage in the area of forest policy processes.

4. Discussion and conclusion

While many recently developed decision support tools have the potential to be used in forest policy-making processes, the use of such tools for this purpose remains limited in Europe. The study showed that quite a large number of forest policy issues exist across European countries; the focus ranged from forest economics to forest roads and infrastructure as well as nature protection. While some issues apply in all countries, others are more context specific and apply in selected countries or are completely absent in others. The analysis also found that in relation to 30 FPAs, no support by any DS tool was provided. In RUS, IRL, CZE, ITA, SWE, TUR and BiH, three or more FPAs were not supported by DS tools.

Furthermore, the research revealed that while a number of DS tools are quite broadly employed across Europe during policy formulation and evaluation activities, usage during policy implementation is very low. Additional analysis identified which attributes characterise FPAs and which attributes are addressed by DS tools. In this context it is also known from many collaborative European projects that several simulators can be used in various ecological contexts (e.g. PICUS -Seidl et al., 2009); SIBYLA -Fabrika and Dursky, 2006), (BWINPro -Nagel and Schmidt, 2006, Linkevičius, 2014, Linkevičius et al., 2014) and DS tools (e.g HEUREKA -Lämås and Eriksson, 2003); AFM Toolbox - Rammer et al., 2014), have been successfully applied in different case studies on climate change adaptation.

Interestingly, some policy target groups (forest owners, the wood industry and NGOs) as well as certain political levels of analysis (international and national), modes of decision making (participatory or hierarchical), and certain goods and services (marketed non-wood products, marketed services) are quite high up the political agenda, but not particularly well addressed by DS tools. In this context it has to be stated, that DS tool development is very often science driven instead of problem driven and this can lead to little or no relevance in terms of addressing policy issues. In addition, trying to incorporate the diverse expectations of various user groups and complex demands from regulatory instruments can lead to the design of very complicated DS tools, which can hamper their applicability and use (Vacik and Lexer, 2014). Conversely, current DS tools addressed certain attributes of policy target groups (scientists, single decision-maker) as well as certain goods and services (marketed wood products, non-market services) to a greater degree than would seem necessary for the current range of forest policy issues. It may be that the existing suite of DS tools was developed in an era before forest policy and forest management issues were expanded to include all productive functions of the forest and all levels of stakeholder input. These results were confirmed in a cross-country analysis; a Spearman's rank correlation revealed a relationship between the order of FPAs as presented in the questionnaire and the number of “not addressed” attributes for these FPAs. The study revealed that a number of DS tools could potentially be used in other countries to address similar forest policy problems. While some tools address more dimensions than others, certain tools could potentially be employed in a higher number of contexts to support decision making.

4.1. DS tools that could potentially address FPAs in other countries

Following categorisation into FPTs, the attributes of all associated FPAs were compared with the attributes of the DS tools, regardless of the country of origin. The DS tool which addressed the most attributes was identified as one that might potentially be useful for all countries with FPAs within that particular FPT Table 4.

The FPAs within the FPT “Forest economics” are addressed by a total of 15 DS tools. The comparison of attributes of the FPAs and DS tools showed that the least number of “not addressed” attributes was achieved by the Portuguese DSS “SADFLOR” Table 4. Thus SADFLOR was identified as the DS tool that could potentially be adopted for use in other countries. This tool also was identified as potentially useful in relation to the FPT “Forest Fires”. In the same way, the simulator “SILVA” was identified as a potential DS tool for the FPTs “Forest ownership”, “Climate change and CO_2” and “Biodiversity and forest usage”. The simulator “KUPOLIS” was identified as potentially useful for the FPT “Restrictions on forest management”. The details of the DS tools that may potentially address the other FPTs are presented in Table 4.

In summary, certain FPTs such as forest economics, climate change and bioenergy are much better addressed by DS tools than others and one DS tool (SADFLOR) and one simulator (SILVA) seem to have the

Table 4
Overview of DS tools that could potentially address similar FPAs in other countries. (NCD – not covered dimensions).

FTPs	Total number of DS tools	Selected DS tool	Type	Country (FPAs)											
				NCDs											
Forest economics	**15**	**SADFLOR (PRT)**	DSS	ESP (3) 1	ESP (5) 0	AUT (5) 0	SVK (5) 1	TUR (3) 1	PRT (1) 0	FIN (4) 0	FIN (1) 0	CZE (3) 0	CZE (5) 1	LTU (1) 1	PRT (5) 0
Forest ownership	**6**	**SILVA (DEU)**	SM	LTU (3) 1	EST (5) 1	IRL (2) 1	SWE (5) 0	DEU (1) 2	PRT (2) 1	ROU (5) 2	SVK (2) 1	SVK (1) 2	PRT (4) 1		
Restrictions on forest management	**4**	**KUPOLIS (LTU)**	SM	EST (1) 1	EST (2) 1	EST (4) 1	IRL (4) 1	LTU (2) 3	LTU (4) 4	LTU (5) 3	SVK (3) 1				
Climate change and CO2	**11**	**SILVA (DEU)**	SM	CZE (1) 2	DEU (2) 2	BGR (3) 2	AUT (3) 3	FRA (2) 2	FRA (3) 2	ITA (5) 2					
National forest programs and strategies	**6**	**WEBBASE SERVICE (FIN)**	DSS	RUS (1) 0	BiH (5) 0	FIN (2) 0	BGR (1) 1	SWE (4) 0	BiH (1) 0	BGR (2) 1	IRL (5) 1	FIN (5) 0			
Afforestation	**7**	**ECOLOGICAL SITE CLASSIFICATION (GBR)**	DSS	IRL (1) 3	TUR (5) 5	CZE (4) 4	GBR (3) 2	GBR (5) 3	BGR (5) 6						
Forest management planning	**5**	**PROGETTOBOSCO (ITA)**	DSS	RUS (3) 3	ROU (4) 1	ITA (4) 3	SVK (4) 1	RUS (2) 3	BGR (4) 5						
Sustainable forest management	**6**	**ECOLOGICAL SITE CLASSIFICATION (GBR)**	DSS	GBR (1) 2	ESP (4) 4	BiH (4) 4	FRA (1) 1	ESP (1) 4							
Bioenergy	**8**	**WEBBASE SERVICE (FIN)**	DSS	EST (3) 0	DEU (4) 3	FIN (3) 0	ITA (2) 0	SWE (2) 1							
Biodiversity and forest usage	**7**	**SILVA (DEU)**	SM	FRA (4) 2	DEU (3) 2	SWE (1) 1	AUT (2) 0	AUT (4) 0							
Illegal cuttings	**1**	**SUMAL (ROU)**	DSS	ROU (1) 7	ITA (3) 4	BiH (3) 4	ROU (2) 1	BiH (2) 3							
Forest fires	**6**	**SADFLOR (PRT)**	DSS	RUS (4) 1	ESP (1) 0	TUR (1) 2	PRT (3) 0								
Natura 2000 constrains	**1**	**MONTE (ESP)**	DSS	AUT (1) 8	ESP (2) 4	ROU (3) 2	ITA (1) 3								
Ecosystem services	**2**	**EFESE (FRA)**	DSS	GBR (2) 2	CZE (2) 3	TUR (4) 2	FRA (5) 3								
Rural areas and land use policy	**4**	**WALDPLANNER (DEU)**	SM	DEU (5) 3	TUR (2) 3	IRL (3) 1	SWE (3) 0								
Forest roads and infrastructure	**5**	**MONTE (ESP)**	DSS	RUS (5) 3	ESP (1) 4	GBR (4) 2									

potential to address a number of issues across a range of countries.

The barriers to more widespread use of DS tools in forest policy making were investigated. A number of limiting factors, some technical and some political (for example, the level of trust of stakeholders and decision makers in employing DS tools and a lack of confidence in the capabilities of those tools), were identified and while these confirm previous research findings (Vacik and Lexer, 2014; Nobre et al., 2016), the analysis also revealed that there are quite a number of specific areas that have not yet been addressed by DS tools. This information may serve to improve the future development of DS tools by highlighting which policy issues could be addressed and focussing attention on the fact that decision makers and stakeholders must be involved to a greater extent in the development of DS tools in order to increase legitimacy and transparency. A contrasting hypothesis could also be formulated, as some decision-making processes might not benefit from a high level of transparency due to the sensitivity of the topic. In such contexts, the use of a DS tool might not be requested by policy makers, as it could perhaps limit the options for negotiations. The analysis also provided insights into which tools are potentially better equipped to address current policy issues notwithstanding the fact that some of these tools may not fully address all required level of analysis.

4.2. Methodological issues

COST Action ORCHESTRA provided a platform to systematically interview forest policy experts and DS tools specialists in a number of European countries. In this way, it was possible to identify the main experts and implement a survey based on their knowledge. However, all the results and findings of this study should primarily be seen as reflection of experts' standpoints. Further study with the broader database would be valuable to adequately portrait the situation.

The first attempt at data collection, by forwarding the questionnaire directly to the policy and DS tools specialists, was somewhat unsuccessful – the response rate was low, many of the questions remained unanswered and there was variability in the interpretation of what information was being sought. For example, policy specialists were not able to answer the questions concerning DS tools and DS tools specialists did not respond to the questions on forest policy. When policy and DS tools specialists were brought together to participate in a Skype meeting with a “moderator”, all questions were thoroughly understood and answered. Depending on the personal field of expertise (e.g. ecology, management, forest protection), the experts who participated might have been more familiar with certain DSS, models, simulators or national forest service systems and this could have biased the analysis to some extent. It should also be noted that it is possible that every expert may not have been aware of all DS tools and FPAs relevant at the national level.

A clear expertise gap between forest policy scholars and DS tool specialists was confirmed and only a few experts indicated expertise in both forest policy and DS tools. This is of key importance in relation to the future development of DS tools as the involvement of forest policy scholars could support DS tool specialists in developing more policy-relevant tools that could be of benefit during decision-making processes. In addition, DS tools specialists can acquaint forest policy scholars with the requirements and capability of DS tools to support forest-related decision-making where forest policy issues are more technical in nature and less politically disputed.

4.3. Understanding

There are many DS tools that have the potential to support policy making. However, there seems to be a mismatch between the development of tools and their current levels of use. One of the explanations for this is the end users' lack of confidence in how to use them effectively and the fact that DS tools are mainly developed by scientists without sufficient interactions with policy makers. These explanations have been addressed in previous studies (e.g. Gordon et al., 2014), and the issue may be resolved by involving forest policy scientists and end-users in the early stages of DS tool development. This would ensure that the tools developed will at least address end-users' needs and most likely end-users will be more inclined to embrace the use of tools that are supported by policy research. Naturally, in order to enhance usability and uptake, appropriate documentation and support services have to be provided (Gordon et al., 2014). According to Vacik and Lexer (2014) despite the fact that a DS tool may use sophisticated techniques and advanced analytics that produce good information, it is highly unlikely that this system will be adopted for use if the policy makers do not fully understand the reasoning that the system is based on. It can therefore be concluded that policy makers, policy scientists and decision support specialists should come together during the early stage of the policy formulation phase to articulate the FPA specifics and clarify the requirements of the DS tool.

The development of computerised quantitative models to support and improve decision making and planning started in the 1960s (Nabuurs and Paivinen, 1996; Reynolds et al., 2005 and Reynolds et al., 2008; Vacik and Lexer, 2014). Since then, different needs and objectives have been incorporated and a large range of different DS tools are available. As issues around land-use change become more important, the demand for computerised tools to support policy making is likely to increase. Another conclusion from our research is that no matter the scale of use (e.g. simple ownership, regional or continental), there is a need to prioritise the development of more user-friendly DS tools. This confirms the findings of Gordon et al. (2014) and Vacik and Lexer (2014).

Decision support tools have the potential of not only helping policy makers and bureaucrats to find consensus in times of uncertainties, but also to support forest policy analysts in gathering deeper and more systematic insights into *how* decisions are made in topical areas that are issue-based while also facilitating the formation of issue-based coalitions. According Mayntz (1993) in issue networks, policy actors are more interested in solving a policy problem (problem solving) and less interested in imposing their interests (bargaining). Therefore, if policy cooperation (and less policy coordination linked to bargaining) prevails, DS tools could potentially be employed to uncouple interests from issues and better inform decision makers. The connections between forest policy scholars and DS tool specialists, which are often quite weak, could potentially be strengthened and used to encourage not only further DS tool development, but also their application in instances where more technical questions prevail and bargaining is not the decisive decision mode. While current levels of trust in these tools might be low, policy makers may be more inclined to use them if issues are apolitical.

4.4. Capacities

An analysis of the capacities of the DS tools to address FPAs was conducted explicitly based on the attributes. Although it could be argued that this approach tries to link two different objects with different spatial distribution, some attributes like “Forest owners” or “Wood industry” are inherent for both for FPAs and DS tools.

The attributes used in this study were adapted from Borges et al. (2014) and, while it could be argued that in doing this, the characteristics of the DS tools were prioritised over those of the FPAs, only overlapping attributes were further analysed. Sharing DS tools or component modules between countries would result in a reduced timeframe for tool development and would allow researchers to concentrate on developing tools to meet new challenges or adapting existing modules to support policy makers rather than ‘reinventing the wheel’. As identified, there are several DS tools in Europe that could be shared for use in different countries; this would be mutually beneficial to both users and developers as it would increase the relevance of these tools. Potential limitations and suggestions on how to address them

have been presented in previous studies (e.g. Gordon et al., 2014) and include the requirement for full documentation to support the tools and that tools should be flexible and not "over-designed". To support an efficient, smooth and successful planning process, a methods and models portfolio that best meets the demands of the current situation should be selected (Vacik et al., 2014). A promising way to combine various DS tools that support different phases of the decision-making process is the "toolbox" approach (cf. Rammer et al., 2014), which will become more important in the future. Considering the constraints of limited funding for DS tool development, a toolbox can be easily adapted and allows continuous development and improvement of the existing tools over several individual project cycles.

The limitations of the study have to be acknowledged including that this was an initial attempt to compare FPAs and DS tools by comparing their attributes. Further qualitative analysis could help to identify more in-depth knowledge in relation to FPAs and DS tools. Since the study did not analyse any country-specific aspects that could limit tools' transfer, the findings have to be read with caution; such aspects could include local needs or expectations of stakeholder groups, local traditions in how forest policy is devised or variations in local forestry standards. Other issues like country-specific climates or levels of data needed to calibrate the models can impact on the potential transferability of DS tools. Additionally, while many tools are based on public licence rules, others are not and the permission of licence holders would be required to render these tools available.

While this study did not analyse any specific property of DS tools, this research improves the awareness of existing tools and prevailing FPAs. It further provides information on how to address the gap between DS tools development and the requirements of policy makers. The exchange of experiences and lessons learned from the development and application of DS tools can be facilitated by the 'Community of Practice of Forest Management Decision Support Systems' (www.forestdss.org), which has a well-established user community from research, public bodies, business and NGOs. It is also hoped that the network of policy and DS tools specialists across European countries which was initiated by the COST Action ORCHESTRA can lead to further cooperative research to address the gaps identified by this study.

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Appendix A. List of all FPAs in analysed countries. (* indicates the FPAs that are not supported by any DS tool)

FPT	FPA	Country (FPA)
1. Forest Economics	1. Activation of market economy	ESP(3)
	2. Low profitability of forestry	ESP (3), PRT (1)
	3. Added value to forests	ESP (3)
	4. Non-wood forest products	ESP (5)
	5. Productivity of forests	AUT (5)
	6. Timber market, potential wood supply and wood processing	SVK (5), CZE (3), FIN (4)
	7. European timber regulations	CZE (5)*
	8. Multiple use of forests	TUR (3)
	9. Management of state forests	LTU (1)
	10. Shortage of applied research	PRT (5)
2. Forest ownership	1. Cooperation of private forest owners	LTU (3)*
	2. Financial or other support or compensations	EST (5), ROU (5), SVK (2), PRT (4)
	3. Nature conservation restrictions	DEU (1), SVK (1)
	4. Property rights versus social interests	SWE (5)*
	5. Lack of thinning in private forests	IRL (2)*
	6. Unknown land ownership	PRT (2)
3. Bureaucratic restrictions on forest management	1. On-going forest restitution	LTU (2)
	2. Stagnant forest policy	LTU (5)
	3. Bureaucracy	LTU (4)
	4. Compensations for restrictions	EST (1)
	5. Clear-cutting age & size restrictions	EST (2, 4)
	6. Restrictions on free access to forest	SVK (3)
	7. Expansion of environmental policies impacting forest management	IRL (4)
4. Climate change and CO2 emissions	1. Climate change mitigation and adaptation	CZE (1), DEU (2), BGR (3), AUT (3), FRA (3)
	2. Low carbon economy and carbon fixation estimates	FRA (2), ITA (5)*

5. National forest programs and strategies	1. Development of forest legislation	RUS (1)*, BIH (1)*, FIN (2), BGR (1, 2)
	2. Shortfalls in legislation or strategies	IRL (5)*, FIN (5)*
	3. Need for & benefits of national forest programme	BIH (5)*, SWE (4)*
6. Afforestation	1. Not achieving afforestation targets	IRL (1)
	2. Ongoing afforestation	CZE (4)*, TUR (5)*
	3. Deep peat restocking	GBR (3)
	4. Ash dieback	GBR(5)
	5. Transformation of plantations to natural forests	BGR (5)
7. Forest management planning	1. Expansion of management tools to address SFM	RUS (3), ITA (4),
	2. Need for national systems for inventory & site classification	ROU (4), RUS (2)*, BGR (4)
	3. Change from State regulated to owner driven planning	SVK (4)
8. SFM - cross sectorial issues like nature protection, water protection and forestry. availability of forest	1. Appropriate species selection	GBR (1)
	2. Appropriate communication of SFM to wider society	ESP (4)
	3. Challenges in achieving SFM	BIH (4)*
	4. Threats of increasing felling rates	FRA (1)
	5. Encouraging active forest management	ESP (1)
Resources and cutting rates		
9. Bioenergy	1. Use of wood in energy production	EST (3), DEU (4)
	3. Development of strategies to address bioenergy sector	FIN (3), ITA (2)
	3. Challenges preparing for the bioeconomy	SWE (2)
10. Biodiversity and forest usage	1. Developing inventories that provide high quality date on biodiversity	FRA (4)*
	2. Achieving balance between biodiversity and production	DEU (3), SWE (1)
	3. Natural disturbances & forest protection	AUT (2, 4)
11. Illegal cuttings	1. Illegal cuttings	ROU (1)
	2. Regulations with regard to EU Timber regulations & forest certification	ITA (3)*,BIH(2, 3)**
	3. Enhanced harvesting & sales procedures	ROU (2)*
12. Forest Fires	1. Number & frequency of forest fires	TUR (1)*, PRT (3)
	2. Need for systems to help control forest fires	RUS (4)*, ESP (1)
13. Natura 2000 constraints	1. Integrating forest management with Natura 2000 constraints	ESP (2), ROU (3)*
	2. Importance of Natura 2000 for the protection of biodiversity	AUT (1)*, ITA (1)*
14. Ecosystem services	1. Quantification of ecosystem services	GBR (2), TUR (4)*
	2. Valuation & payments for ecosystem services	CZE (2)*, FRA (5)
15. Rural areas & landuse policy	1. Forestry & rural development	DEU (5), TUR (2)*
	2. Forest and agriculture policies in term of land availability	IRL (3)*
	3. Landuse conflicts with indigenous peoples	SWE (3)*
16. Forest roads & infrastructure	1. Development of adequate forest road infrastructure	RUS (5), ESP (1)
	2. Issues of stability & long term planning	GBR (4)

Appendix B. Clarification of dimensions and attributes that were not addressed by DS tools for each country and its FPAs. (FPAS, supported by no DS tool is not listed here)

		5 DS tools			4 DS tools				3 DS tools			2 DS tools			1 DS tool				0
dimensions	**attributes**	**ESP**	**GBR**	**BGR**	**AUT**	**DEU**	**PRT**	**FRA**	**EST**	**ROU**	**CZE**	**LTU**	**FIN**	**RUS**	**ITA**	**IRL**	**SWE**	**TUR**	**BiH**
		number of FPA (relates with table presented in Appendix A)																	
Policy target group	forest owners							1 2 5	1 2	1 5							1 2		
	wood industry				2 3 5			1 2	2		1				2 4		1 2		
	scientists		5		4					1 4						4	1 2		
	NGOs	2 4 5	3 5		3			1 2 3		1	1		2		4	4	1 2		
	policy DM	2 3 4 5	4		2 4 5			3		1								3	
Spatial scale	international	3	5	4		1 2 3 4 5		5				1 4						3	
	national	3 4 5			5	1 2		3							2				
	regional	2 3 4 5			4			3							2 4	4		3	
	community	1 2 4 5			4			1		1		4			4	4		3	
	landscape				4			5				4					1 2		
	stand							2		4		4					1 2		
	single tree		1							1									
Decision makers (DM)	participatory				4			3	2	1				3					
	> 1 DM		3							5	1					4		3	
	Only 1 DM								1								1 2		
Goods and services addressed	market NWFP			1 2 3 4 5	3 5	5				5		2	1	5	4			3	
	market timber																		
	market services				2 3 4		3					2	1 2	5		1 4	1 2	3	
	non market		1						1			2	1 2	5					

References

Arts, B., 2012. Forests policy analysis and theory use: overview and trends. For. Policy Econ. 16, 7–13. http://dx.doi.org/10.1016/j.forpol.2010.12.003.

Arts, B., Appelstrand, M., Kleinschmit, D., Pülzl, H., Vissen-Hamakers, I., Eba'a Atyi, R., Enters, T., Mcginley, K., Yasmi, Y., 2010. Discources, actors and instruments in international forest governance. Embrac. Complex. Meet. Challenges Int. For. Gov. 28, 57–73.

Borges, J.G., Nordström, E.M., Garcia-Gonzalo, J., Hujala, T., Trasobares, a., 2014. Computer-based tools for supporting forest management. In: The Experience and the Expertise World-Wide.

Borges, J.G., Marques, S., Garcia-Gonzalo, J., Rahman, A.U., Bushenkov, V., Sottomayor, M., Carvalho, P.O., Nordström, E.-M., 2017. A multiple criteria approach for negotiating ecosystem services supply targets and forest owners' programs. For. Sci. 63.

Burstein, F., Holsapple, C., 2008. Handbook on Decision Support Systems 2: Variations. Springer Science & Business Media.

Cintas, O., Berndes, G., Cowie, A.L., Egnell, G., Holmström, H., Ågren, G.I., 2016. The climate effect of increased forest bioenergy use in Sweden: evaluation at different spatial and temporal scales. Wiley Interdiscip. Rev. Energy Environ. 5, 351–369.

Corrigan, E., Nieuwenhuis, M., 2016. Using goal-programming to model the effect of stakeholder determined policy and industry changes on the future management of and ecosystem services provision by Ireland's western peatland forests. Sustainability 9, 11.

Dobšinská, Z., Rathke, J., Weber, N., 2015. COST FP 1207 : Orchestrating Forest-Related Policy Analysis in Europe (ORCHESTRA) Synthesis Report of WG1 Country Reports.

EC, 2013. A New EU Forest Strategy: For Forests and the Forest-Based Sector. (Com).

Eggers, J., Holmström, H., Lämås, T., Lind, T., Öhman, K., 2015. Accounting for a diverse forest ownership structure in projections of forest sustainability indicators. Forests 6, 4001–4033.

Eriksson, L.O., Borges, J.G., 2014. Computerized decision support tools to address forest management planning problems: history and approach for assessing the state of art world-wide. Comput. Tools Support. For. Manag. Exp. Expert. World-Wide 3–25.

Europe, F., Unece, F.A.O., 2015. State of Europe's forests 2015. Status trends Sustain. For. Manag. Eur. 314. http://www.foresteurope.org/docs/fullsoef2015.pdf.

Fabrika, M., Dursky, J., 2006. Implementing tree growth models in Slovakia. In: Sustainable Forest Management. Springer, pp. 315–341.

Fiore, S.M., Harrsion, G.W., Hughes, C.E., Rutstrom, E.E., 2007. Virtual Experiments and Enviromental Policy. {RFF/EPA} Conf. http://dx.doi.org/10.1016/j.jeem.2008.08.002.

Geitzenauer, M., Blondet, M., de Koning, J., Ferranti, F., Sotirov, M., Weiss, G., Winkel, G., 2017. The challenge of financing the implementation of Natura 2000 – empirical evidence from six European Union member states. For. Policy Econ. 82, 3–13. http://dx.doi.org/10.1016/j.forpol.2017.03.008.

Gordon, S.N., Floris, A., Boerboom, L., Lämås, T., Eriksson, L.O., Nieuwenhuis, M., Garcia, J., Rodriguez, L., 2014. Studying the use of forest management decision support systems: an initial synthesis of lessons learned from case studies compiled using a semantic wiki. Scand. J. For. Res. 29, 44–55. http://dx.doi.org/10.1080/02827581.2013.856463.

Jaakko Poyry Consulting, I., 1994. Proposed Final Generic Environmental Impact Statement on Timber Harvesting and Management in Minnesota. Minnesota Environ Qual Board Var Pagings, St. Paul, MN.

Kilgore, M.A., 1992. Government response to sensitive timber harvesting issues: minnesota generic environmental impact statement. In: Conference Proceedings: Forestry and the Environment: An International Perspective.

Kilgore, M.A., Ek, A.R., 2007. Cumulative Forestry Impact Assessments: Lessons Learned and Planning for States.

Krott, M., 2005. Forest Policy Analysis. Springer Science & Business Media.

Lämås, T., Eriksson, L.O., 2003. Analysis and planning systems for multiresource, sustainable forestry: the Heureka research programme at SLU. Can. J. For. Res. 33, 500–508.

Lämås, T., Sandström, E., Jonzén, J., Olsson, H., Gustafsson, L., 2015. Tree retention practices in boreal forests: what kind of future landscapes are we creating? Scand. J. For. Res. 30, 526–537. http://dx.doi.org/10.1080/02827581.2015.1028435.

Leipold, S., 2017. How to move companies to source responsibly? German implementation of the European timber regulation between persuasion and coercion. For. Policy Econ. 82, 41–51. http://dx.doi.org/10.1016/j.forpol.2016.11.009.

Linkevičius, E., 2014. Single Tree Level Simulator for Lituanian Pine Forests.

Linkevičius, E., Kuliešis, A., Röhle, H., Schröder, J., Aleinikovas, M., 2014. The impact of competition for growing space on diameter, basal area and height growth in pine trees. Balt. For. 20.

Lovrić, N., Lovrić, M., Konold, W., 2018. A grounded theory approach for deconstructing the role of participation in spatial planning: insights from Nature Park Medvednica, Croatia. For. Policy Econ. 87, 20–34. http://dx.doi.org/10.1016/j.forpol.2017.11.003.

Marques, A.F., Borges, J.G., Sousa, P., Pinho, A.M., 2011. An enterprise architecture approach to forest management support systems design: an application to pulpwood supply management in Portugal. Eur. J. For. Res. 130, 935–948. http://dx.doi.org/10.1007/s10342-011-0482-8.

Marques, A.F., Borges, J.G., Garcia-Gonzalo, J., Lucas, B., Melo, I., 2013. A participatory approach to design a toolbox to support forest management planning at regional level. For. Syst. 22, 340. http://dx.doi.org/10.5424/fs/2013222-03120.

Maryudi, A., Sahide, M.A.K., 2017. Research trend: power analyses in polycentric and multi-level forest governance. For. Policy Econ. 81, 65–68. http://dx.doi.org/10.1016/j.forpol.2017.05.003.

Mayntz, R., 1993. Policy-netzwerke und die logik von verhandlungssystemen. In: Policy-Analyse. Springer, pp. 39–56.

Menzel, S., Nordström, E.-M., Buchecker, M., Marques, A., Saarikoski, H., Kangas, A., 2012. Decision support systems in forest management: requirements from a participatory planning perspective. Eur. J. For. Res. 131, 1367–1379.

Nabuurs, G.-J., Paivinen, R., 1996. Large Scale Forestry Scenario Models; a Compilation and Review.

Nagel, J., Schmidt, M., 2006. The silvicultural decision support system BWINPro. In: Sustainable Forest Management. Springer, pp. 59–63.

Nobre, S., Eriksson, L.-O., Trubins, R., 2016. The use of decision support systems in forest management: analysis of forsys country reports. Forests 7, 72.

Orazio, C., Montoya, R.C., Régolini, M., Borges, J.G., Garcia-Gonzalo, J., Barreiro, S., Botequim, B., Marques, S., Sedmák, R., Smreček, R., Brodrechtová, Y., Brukas, V., Chirici, G., Marchetti, M., Moshammer, R., Biber, P., Corrigan, E., Eriksson, L.O., Favero, M., Galev, E., Hengeveld, G.M., Kavaliauskas, M., Mozgeris, G., Navrátil, R., Nieuwenhuis, M., Paligorov, I., Pettenella, D., Stanislovaitis, A., Tomé, M., Trubins, R., Tuček, J., Vizzarri, M., Wallin, I., Pretzsch, H., Sallnäs, O., 2017. Decision support tools and strategies to simulate forest landscape evolutions integrating forest owner behaviour: a review from the case studies of the European project, INTEGRAL. Sustain. For. 9. http://dx.doi.org/10.3390/su9040599.

Pretzsch, H., Biber, P., Dursk, J., 2002. The single tree based stand simulator SILVA: construction, application and evaluation. For. Ecol. Manag. 162, 3–21.

Pülzl, H., Wydra, D., 2014. Waldrelevante Politiken und Gesetze der Europaischen Union - eine Evaluierung. Project Report. European Forest Institute. Central-East European Regional Office EFICEEC, Vienna, pp. 162. http://www.eficeec.efi.int/files/attachments/eficeec/library/reports/europa_ische_waldpolitik_april_2014_final.pdf.

Pülzl, H., Kleinschmit, D., Arts, B., 2014. Bioeconomy – an emerging meta-discourse affecting forest discourses? Scand. J. For. Res. 29, 386–393. http://dx.doi.org/10.1080/02827581.2014.920044.

Rammer, W., Schauflinger, C., Vacik, H., Palma, J.H.N., Garcia-Gonzalo, J., Borges, J.G., Lexer, M.J., 2014. A web-based ToolBox approach to support adaptive forest management under climate change. Scand. J. For. Res. 29, 96–107. http://dx.doi.org/10.1080/02827581.2013.851277.

Reynolds, K.M., Borges, J.G., Vacik, H., Lexer, M.., Hetemaki, L., Nilsson, S., 2005. Information and communication technology in forest management and conservation. In: Information Technology and the Forest Sector. IUFRO World Series, vol. 18. International Union of Forest Research Organizations, Vienna, Austria, pp. 150–171.

Reynolds, K.M., Twery, M., Lexer, M.J., Vacik, H., Ray, D., Shao, G., Borges, J.G., 2008. Decision support systems in forest management. In: Handbook on Decision Support Systems 2. Springer, pp. 499–533.

Rose, D.W., McDill, M., Hoganson, H., 1993. Development of an environmental impact statement of forestry programs: a Minnesota case study. Compil 10, 18–27.

Seidl, R., Schelhaas, M.J., Lindner, M., Lexer, M.J., 2009. Modelling bark beetle disturbances in a large scale forest scenario model to assess climate change impacts and evaluate adaptive management strategies. Reg. Environ. Chang. 9, 101–119. http://dx.doi.org/10.1007/s10113-008-0068-2.

Sotirov, M., Winkel, G., 2016. Toward a cognitive theory of shifting coalitions and policy change: linking the advocacy coalition framework and cultural theory. Policy. Sci. 49, 125–154.

Sotirov, M., Stelter, M., Winkel, G., 2017. The emergence of the European Union timber regulation: how Baptists, bootleggers, devil shifting and moral legitimacy drive change in the environmental governance of global timber trade. For. Forest Policy Econ. 81, 69–81. http://dx.doi.org/10.1016/j.forpol.2017.05.001.

Vacik, H., Lexer, M.J., 2014. Past, current and future drivers for the development of decision support systems in forest management. Scand. J. For. Res. 29, 2–19. http://dx.doi.org/10.1080/02827581.2013.830768.

Vacik, H., Kurttila, M., Hujala, T., Khadka, C., Haara, A., Pykäläinen, J., Honkakoski, P., Wolfslehner, B., Tikkanen, J., 2014. Evaluating collaborative planning methods supporting programme-based planning in natural resource management. J. Environ. Manag. 144, 304–315.

Zar, J.H., 2013. Biostatistical Analysis: Pearson New International Edition. Pearson Higher Ed.