Common Agricultural and wider bioeconomy reSearch Agenda

SYNTHESIS ON FOREST BIOECONOMY RESEARCH AND INNOVATION IN EUROPE

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1. EXECUTIVE SUMMARY

In order to address challenges linked to fossil-based economy, EU has made a strategic turn towards bioeconomy, which is characterized by usage of renewable biomass. The European forest-based sector can contribute substantially to these structural changes. But this will need research and innovation at all levels. It therefore should develop capacities and research infrastructures which will be able to address relevant questions in the new policy setting. Although several research capacity mappings have been conducted, none has been produced so far that encompass the diverse range of forest bioeconomy topics, from forest inventory to fiber technologies. Another challenge in planning European forest research is that there is no review of European research activity in the field of forest bioeconomy. The EU Framework Programme H2020 puts equal emphasis on research and innovation, where innovation is the mechanism through which companies can adapt to bioeconomy-related challenges. However, there is no systematic review of organizational-level innovations in the field of forest bioeconomy. This reports tackles these challenges by (I) compiling previous research capacity mapping exercises; (II) mapping research activity in the field as based on FP7, H2020 and ERA-NET projects, and (III) maps organizational-level innovations in the field, along with factors that affect their development. The report ends with policy-level recommendations from all three sections.

For the purpose of this study, the **Forest bioeconomy** is defined by four main categories, following a supply-chain logic (Forest systems; Forest biomass & raw materials; Primary processing; Secondary processing). Mapping of research capacities is based on six previous mapping exercises, while the research activity and innovation mapping in forest bioeconomy are obtained from research and innovation project contained in the EC's CORDIS data base.

From the mapping of research capacities, results show that **capacities increase along the supply-chain of forest bioeconomy** (e.g. there are more capacities in secondary processing than in forest management), and they also increase from South-East to North-West of Europe. Although each European region has proportional capacity in each segment of forest bioeconomy, **Southern Europe has highest capacities in primary processing, while Western and Northern Europe have highest capacities in secondary processing**. Topic-level capacities vary greatly on European level, and they are most strongly pronounced for topic of pretreatment technologies, followed by forest inventory and economics, forest management, wood processing and biopolymer processing. The distribution of country-level capacities is highly uneven, as **Sweden, Germany, Finland, France and Spain together account for 49% of total mapped research capacities**. Seven out of ten organizations with highest overall capacities are located in the Nordic countries.

The forest bioeconomy research activity as seen through CORDIS-listed projects shows participation of 1978 organizations in the 2008-2017 period, with a total value of projects of 1.4 billion Euros. **The annual value of approved projects increases** through the observed period, and also along the supply-chain categories. Distribution of research funding by topic is uneven. The **dominant topics bioenergy, biorefinery, construction and final wood products and sustainability assessment** have received more than one hundred million of Euros each. The topics for which the funding has substantially increased in H2020 are sustainability assessment, wood supply chain and downstream processing, while the topics for which the funding has substantially decreased in H2020 are forest inventory and economics, forest ecosystem services, non-wood forest products and wood properties. Topics that have significantly more funding than research capacities are: sustainability

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assessment, forest ecosystem services, bioenergy, construction and final wood products, other bio-based/high value products and biorefinery. Topics that have significantly less funding than research capacities are forest inventory and economics, wood properties, wood processing, pretreatment technologies, pulping, chemical conversion, biopolymer processing and downstream processing. When EC funding is aggregated on country level, Germany is at the top (128 mil. €), followed by Sweden (108 mil. €), Finland (98 mil. €) and France (88 mil. €). **The organizations that have received highest level of funding are located in Western and Northern Europe**. While funding in more forestry-related topic is almost exclusively provided to research and higher-education organizations, **about half of the total funding is devoted to private companies in the latter stages of supply-chain** (i.e. primary and secondary processing). Analysis of cooperation between individual organizations shows that the **cooperation networks are highly centralized**, i.e. that few organizations such as European Forest Institute and INRA have participated in many projects and have collaborated with many other organizations, while majority of organizations have very limited number of project participations. The analysis also shows that **forest bioeconomy is not really a research-field on its own**, and that each of its four supply-chain categories are dominated by different groups of organizations that rarely collaborate between themselves. On country level analysis of collaboration, in all four categories of the supply-chain classification Germany, Finland and France are in the centre, followed by Italy, UK, Sweden, Netherlands and Spain.

From the mapping of innovation activity, **production method was the most frequent type of innovation, followed by goods and services**. All other types of innovation are represented with less than 10 percent of occurrence, with the exception of business practice / modes. **The share of innovations by stages of development steadily grows from initial idea generation to design and development, only to strongly decrease in the subsequent stages**. In the vast majority of cases, innovation development required a high degree of cooperation between different actors, a complex knowledge base, and was an iterative, complex, non-linear process. Respondents have stated that in general, their organizations were supportive of innovation development, mostly in terms of productive innovation teams, and least in terms of organizational resources. The development of the sampled innovation cases was also characterized by collaboration with different external groups of actors, most notable with universities and research institutes. When it comes to resource-based support for development of innovations, relevant information was easily accessible – but that was not the case with material and financial resources. **Vast majority of respondents considers EU projects as a useful tool for innovation development, and majority of innovation cases were characterized as success**. Comparing factors behind innovation development for successful and unsuccessful cases, the main discriminating characteristics of successful innovations are: they are disruptive and radically new, have received adequate external financial support, have enjoyed pronounced support from organizational leadership, and were developed in cooperation with a wide array of different groups of actors. **Private companies generate between three and six Euros of revenue from innovations developed in EC's projects from every Euro that they have received as EC funding**. As based on the overall sample data, EC has invested about three hundred thousand Euros per single patent or patent application.

From the study results, several policy-relevant conclusions can be drawn:

- Forest bioeconomy is a very fragmented research area, and there is low level of cooperation among different topics

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- Eastern Europe has received low level of EC's funding compared to its capacities, and its organizations are only marginally involved in the European research network. There are only few innovation cases that are close to commercialization, while majority of cases are in the initial stages of innovation development
- Most innovations are successful, and EC funded project offer a useful framework for their development
- Radically new and complex innovations are more successful than routine and 'safe' innovations
- Information on innovations provided in EC projects is not enough to develop successful innovations; they need also adequate financial support, as well as input from diverse groups of actors

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2. INTRODUCTION

The EU has taken a strategic turn towards bioeconomy (EU 2020 Strategy, 2010), which has also influenced the EU research and development orientation, by putting more emphasis on bioeconomy related research and activities (EU Bioeconomy strategy, 2012). Although the concept can be defined in different ways (Pfau et al, 2014; Pülzl et al, 2014; Vandermeulen et al, 2012), the core characteristic is the strong reliance on renewable biomass (Ollikainen, 2014; Pfau et al, 2014; Johnson and Altman, 2014). The European forest-based sector can contribute substantially to these structural changes. But this will need research and innovation at all levels. It therefore should develop capacities and research infrastructures which will be able to address relevant questions in the new policy setting.

Although a number of forest research capacity mapping exercises have been conducted at EU level, it remains unclear how far the bioeconomy research is addressed in these mapping exercises. An overall synthesis based on updated information on forest bioeconomy research and innovation covering the complete forest-based systems is thus missing for Europe. Such a synthesis would serve several important purposes: 1) It would be an important baseline for future strategic advice and new initiatives from the SWG to strengthen coordination in research and innovation work between the EU, member states and stakeholders; 2) it would be of great use for alignment and for reference in the design and framing of European and national calls within the area, and 3) it would constitute an important strategic document in relation to the developing overall European bioeconomy strategy. This study shall contribute to better synergies and coherence for addressing research needs in the forest-based bioeconomy by (1) mapping the most relevant research capacities and topics where activities are already ongoing at regional/national, transnational and European level using existing data, and (2) analysing gaps and draw conclusions about overlapping and missing activities, and trends and shifts in research focus.

Besides coherent information and analysis of research capacities in the Forest Bioeconomy sector, it also remains unclear what type of innovations are supported through current EU funded research and innovation activates and how successful are they. Studies focusing on organizational-level innovations in the field bioeconomy are rare (Golembiewski et al, 2015). These innovation range from small and gradual changes (European Commission, 2012; Boons et al, 2013) to totally new and radical innovations (Boehlje and Broring, 2011, Golembiewski, et al, 2015; Kleinschmit et al, 2014). In this study we tackle this shortcoming with an attempt to map innovations in the field of forest bioeconomy. The targeted population of firms with cases of innovation in the field of forest bioeconomy is proxied with the sampling frame of all private companies that have participated in EU co-funded research and innovation projects within the field of forest bioeconomy The objectives of the study are (1) to map what kind of innovations are present in the field of bioeconomy and (2) what internal and external factors frame their development. Such analysis will contribute to identification of most successful innovations (i.e. best practice examples), and of factors that have supported their development. Presenting a list of these innovation-enabling factors may have great policy relevance, as fostering of them may be incorporated into EC's strategic planning of future research and innovation agendas.

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3. MATERIALS AND METHODS

3.1. Mapping forest bioeconomy research capacities in Europe

First step in mapping forest bioeconomy capacities in Europe was to define what the concept of forest bioeconomy entails. According to the EU Bioeconomy Strategy, bioeconomy encompasses *"… the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production as well as parts of chemical, biotechnological and energy industries*." As such, forest bioeconomy is a sub-section of the wider bioeconomy concept. In this study an analytical definition of forest bioeconomy is taken-up, where the initial step was to list all topics that describe forestry and its wider connections to all other sectors encompassed within bioceconomy. These 151 topics are compiled from the following research capacity mapping exercises: ERIFORE project (http://erifore.eu/) and its bibliometric study (see deliverable 1.2), mapping in the ERA-Net projects WOODWISDOM (http://www.woodwisdom.net/), FORESTERRA (http://www.foresterra.eu/), INNOVAWOOD (http://www.innovawood.com/) and SUMFOREST (https://www.sumforest.org/) Five senior researchers in the field then jointly defined which specific topics are entailed within the concept of forest bioeconomy. 106 topics have been included in the analytical definition of the concept. In order to group all these topics, a supply-chain type classification has been developed that entails four categories and 21 topics (Table 1), which to a large extent follows ERIFORE's supply chain classification. The sub-topics and examples of projects in different topics are presented in Appendix I, which also contains a map of Europe with regional categorization of countries.

Table 1. Classification of forest bio-economy

CATEGORY	TOPIC
1.FOREST SYSTEMS	1.1.Forest inventory and economics
	1.2.Sustainability assessment
	1.3.Forest ecosystem services
	1.4.Non-wood forest products
2. FOREST BIOMASS & RAW MATERIALS	2.1.Forest management
	2.2.Tree breeding and forest biotechnology
	2.3.Wood properties
	2.4.Wood supply chain
	2.5.Recycled wood and fibres
3. PRIMARY PROCESSING	3.1.Wood processing
	3.2.Pretreatment technologies
	3.3.Pulping
	3.4.Bioenergy
4. SECONDARY PROCESSING	4.1.Construction and final wood products
	4.2.Chemical conversion
	4.3.Bioprocessing and biotechnology
	4.4.Biopolymer processing
	4.5.Fiber technologies
	4.6.Other bio-based final / high value products
	4.7.Biorefinery

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	4.8.Downstream processing

After the classification has been designed, all deliverables of the projects mentioned above have been analysed. If a given organization has been described as having capacities on a given topic, this instance has been marked with number one. Initial idea was to simply sum the organizational capacities on a given topic for all such organizations in a country in order to get country-level capacities on a given topic. It quickly became apparent that this procedure is not adequate, as not all topics and countries are present in all mapping exercise. Figures 1 and 2 show frequency of topics and countries across mapping exercises.

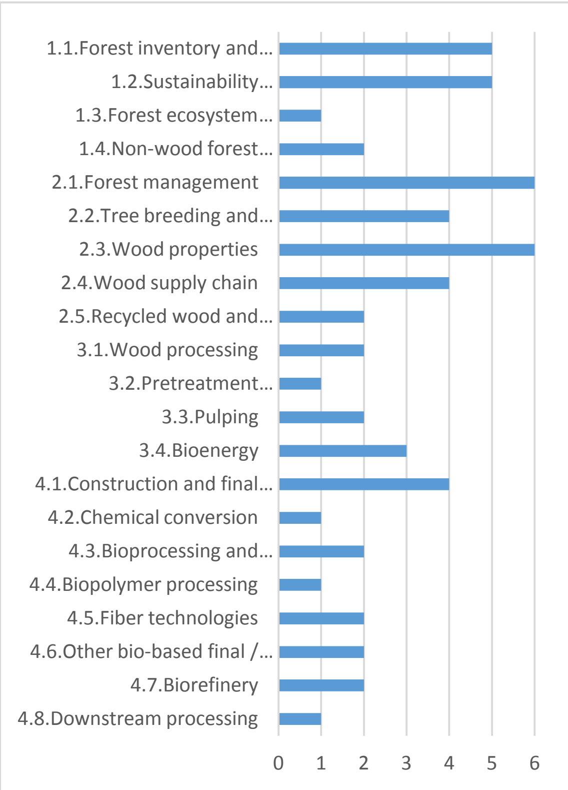

Figure 1. Frequency of topics in mapping exercises

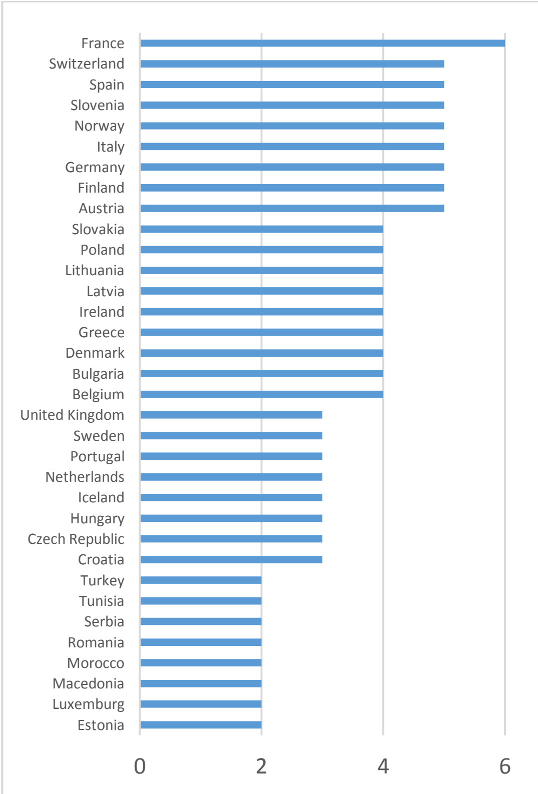

Figure 2. Frequency of countries in mapping exercises

In order to assess the capacities in forest bioeconomy research, a normalization by topic and country has been performed. The score for a given topic of a single organization ranges from 0 to 1, and represents the share of mapping exercises in which the topic-capacity has been attributed, with respect to the number of mapping exercises in which the given topic and country have been present. For example, for the French National Institute of Agricultural Research (INRA) capacity in topic 1.1. (Forest inventory and economics) has been marked in four different mapping exercises. France was present in all six mapping exercises, while topic 1.1. was present in five of them. This results with INRA having 0.8 points in topic 1.1., i.e. 4/5. For the Croatian Forest Research Institute (CFRI) capacity in topic 2.1 (Forest management) has been marked in two different mapping exercises. Croatia was present in three mapping exercises and all of them also included topic 2.1. This results with CFRI having 0.67 points in topic 2.1, i.e. 2/3. National capacities for a given topic have been gained by summing up points for that topic from all organizations in that country. In FORESTERRA (deliverable 2.4) national research programmes were presented in percentages, while FORESTERRA data base on research capacities (http://www.foresterra.eu/tablas/investigacion.php)

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lists different characteristics of organizations encompassed in the mapping, such as overall budget, number of permanent staff, number of publications and projects per year. In order to assign forest bioeconomy topic-specific capacities, percentages of national research capacities have been multiplied with the number of research organizations in the country. The topic-specific capacities have been assigned to organizations starting with the one that has highest number of permanent forestry staff. All results smaller than one are treated as topic-specific research capacity of one organization (i.e. the one with highest number of permanent staff). Research capacities of organizations from other continents are not taken into consideration.

Data sources for mapping of research capacities include deliverables 1.1, 1.2, 2.1, 2.2, 3.1, 3.2, 4.1 and 4.2 of ERIFORE project (http://erifore.eu/), from WoodWisdom project (http://www.woodwisdom.net/) report No. 02/2006, from FORESTERRA project (http://www.foresterra.eu/) deliverable 2.4 and its data base on research capacities (http://www.foresterra.eu/tablas/investigacion.php), from INNOVAWOOD project (http://www.innovawood.com/) its search engine of research providers (http://77.74.50.56/ssa/default.aspx and http://www.innovawood-ssa.net/), and from SUMFOREST project (https://www.sumforest.org/) deliverables 2.1 and 2.2.

3.2. Mapping forest bioeconomy research activity in Europe

Forest bioeconomy research activity has been proxied by research activity in EC's framework programmes (FP7, H2020 and ERA-NETs). Data sets of the CODRIS database were retrieved on 24.5.2017. Main data-types are one to several paragraphs long project descriptions that summarizes objectives (column objective), unique project and organization identification codes, list of organizations in the project consortia and their type, total project funding and EC's funding by project partner.

As the sampling frame is too large to be manually reviewed (25607 projects in FP7 and 11070 projects in H2020), a semi-automatic sampling procedure has been developed, where each project description in the data sets has been compared to the 'core' description of the forest bio-economy. First part of the 'core' forest bioeconomy description is the 12-page long description of all the topics contained in the classification developed to map research capacities. This text is to a large extent based on topic descriptions as designed in the ERIFORE project (see deliverables 1.2, 2.2, 3.2 and 4.2). The second part of the 'core' forest bioeconomy description is a 42-page long compilation of all project abstracts that fit the sample from FP7 and H2020 as listed in the project database of the Forest-based Sector's Technology Platform (http://db.forestplatform.org). This combined 'core' forest bioeconomy description together with project objectives of all FP7 and H2020 has been imported to R programming environment, and the two have been compared with Text Mining package. The 'core' forest bioeconomy description was 'cleaned' from 'stop-words' (e.g. "the", "and", "will", "for", "from", "this", "are", "that", etc.), and then transformed into lemmatized strings (roots of words, e.g. manage for management, manager, etc.) i.e. 'key words' (only nouns and verbs). All string with frequency 20 and higher have been used in analysis (total of 244). The comparison between the project description is based on frequency of joint strings (e.g. if only one string appears only once in two projects, than their similarity is 1). The similarity between 'core'

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forest bioeconomy description and a given project is set by multiplying the frequency of shared strings with the frequency of that string in the 'core' forest bioeconomy description. Example: string 'forest' is mentioned in the 54-page 'core' forest bioeconomy description 315 times. Frequency of 'forest' in description of project FORGER (Towards the Sustainable Management of Forest Genetic Resources in Europe) is 9. This makes their similarity score for string 'forest' 2835 (i.e. 315 x 9). Same procedure is done for all 244 strings. Different indexes of similarity are gained by adding-up similarity scores for similarity of individual strings. For comparison between 'core' forest bioeconomy description and all other projects, similarity scores for strings 'forest', 'wood', top 10 strings, top 50 strings, top 100 strings and all 244 strings have been used. All the projects in FP7 and H2020 were then ranked from most to least similar according to these indexes in the order as they were written. Project descriptions were then read, and those which fit to the sample were selected. The review of the project descriptions stopped when 100 successive projects did not fit the sample. All the FP7 and H2020 project were then re-ordered according to the subsequent index from highest to the lowest score, excluding the ones that were previously sampled. The same procedure of reviewing the projects was repeated for all indexes. Bio-Based Industries Joint Undertaking projects are included in the data set. ERA-NET projects that fit the sample were not included in the data set – but rather all the projects funded within such ERA-NET were individually reviewed, and if found fitting to the topic of forest bio-economy, were included in the list of sampled projects. This procedure resulted with 387 sampled projects.

The sampled project descriptions were then compared to the descriptions of individual topics and classified accordingly. In the CORDIS data set, project partners were named inconsistently across projects – they were named on different languages, had small differences in typing, marked on different levels of organizational complexity (e.g. institutes within a single faculty, faculty or university). All organizations listed in the data set were checked for consistency that same organizational names are used in different projects, and where appropriate, organizations were aggregated to a higher level of complexity. Examples: single Fraunhofer Society is named, which previously was Institute for Interfacial Engineering and Biotechnology; Institute for Wood Research; Institute for Environmental, Safety and Energy Technology; Center for Chemical-Biotechnological Processes and Institute for Chemical Technology. Branches or regional departments of a single organization have been pooled together – e.g. EFI Central European Regional Office and the EFI Observatory for European Forests are both renamed to EFI. Organizations that have changed names and/or had mergers are renamed to current organizational name – for example METLA (Metsäntutkimuslaitos - Finnish Forest Research Institute) was renamed to LUKE (Luonnonvarakeskus - Natural Resources Institute Finland), and both University of Joensuu and the University of Kuopio have been renamed to University of Eastern Finland (which was formed by the merger of the two). Companies and subsidiaries of larger organizations are renamed to their parent organizations. Examples: Biofuel Technology Center is renamed to Swedish University of Agricultural Sciences and Laboratoired'étudeset de recherche sur le matériau bois is renamed to University of Lorraine. All companies (incorporated, limited company, limited liability company, corporation limited by share ownership, etc.) are marked with additional variable. This was already present in CORDIS data base for most FP7 and H2020 project partners, but not for ERA-NET project partners. CORDIS data base contains total project funding and EC's funding by project partner. Total funding by project partner is used for ERA-NET projects, and summed up with partner EC's funding in other projects to aggregate funding results on national level. All values of total funding and EC's funding are expressed as 2017 constant values based on Eurozone's inflation rates. For the third WOODWISDOM call (2011-2014) only overall budget (18.5 mil. €) is available; and this overall figure

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was distributed equally among the projects and their participants. EC's funding was also not specified for 34 projects listed in the CODRIS data set; only overall project funding figures were available. For these projects, average EC's funding rate from all sampled projects was applied, and the total EC's funding was then equally distributed among their participants. Descriptive data analysis has been performed, both for research capacities and research activity as displayed by participation in research projects. Only minor segment of possible cross-tabulations between available variables have been displayed; and they have been selected for revealing important characteristics of the data. Analysis of collaboration between countries and individual organizations is based on procedures of Social Network Analysis (SNA). In this report, SNA is used just as an exploratory tool, where only degree-distribution effect is taken into consideration, i.e. the number of joint participations in research projects. The graph visualizations of collaboration between organizations are set in spring-embedded layout, which allows for quick identification of central and peripheral organizations in the collaboration network; as those organizations that frequently collaborate are placed close to one another, and 'central' (strongly interconnected to everyone else) organizations are placed in the centre of the graphs.

The comparison between the research capacities and research activity serves as a gap analysis, i.e. reveals the potential areas of mismatch between research capacities and actual research activity, with respect to topical and geographical distribution. Same type of descriptive data analysis has been performed on both data types (research capacity and activity), in order to enable the comparison between the two. Additional descriptive collaboration analysis in research activity has been performed, which is based on counting joint participation in projects between individual organizations and countries.

3.3. Mapping innovations in forest bioeconomy in Europe

One of the goals of this study is to support policy makers in enhancing the innovation development in the field of forest bioeconomy. To that end, in the design of this study, the open innovation (Chesbrough, 2006) is taken-up as the primary concept, which can be defined as *"…a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology*" (p. xxiv). The main idea in the open innovation concept is that the innovation development also strongly depends on many variables outside the innovating organization, such as resource-based support and cooperation with universities. These, external variables, can be easier to influence by external stakeholders such as policy makers than the internal organizational variables. We follow the approach of Van Lancker et al. (2016) in defining innovation-related variables in the field of bioeconomy, while outputs of innovation are treated as dependent variables. The main outline of the study is presented by the 'formula' below and Table 2.

DESCRIPTION OF INNOVATION + INTERNAL VARIABLES + EXTERNAL VARIABLES + DESCRIPTION OF ORGANIZATION = OUTPUTS OF INNOVATION

Where all of the introduced variables are backed by relevant literature (Huston and Sakkab, 2004; Chesbrough, 2004; Giannopoulou et al, 2011; Holl and Rama, 2012; Du et al, 2014; Kutvonen, 2011; Schaltegger et al, 2013; Malerba, 2002; Cooke et al, 1997).

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Table 2.Variables in the mapping of forest bioeconomy innovations

VARIABLE	REFERECES	COMMENTS
1. Description of innovation		
1.1. Type of innovation	OECD, 2005	
1.2. Stage of innovation development	Gopalakrishnanand Damanpour, 1997	as based on the referenced review publication
1.3. Technological Readiness Level of innovation	Mankins, 1995	as based on basic characteristics of TRL scales
1.4. Extent to which innovation was disruptive or radically new	Boons et al, 2013; Boehlje and Broring, 2011; Golembiewski et al, 2015; Kleinschmit et al, 2015; Pülzl et al, 2014; Staffas et al, 2013; Kirchen, 2012	
1.5. Level of complexity in the knowledge base for the innovation development	Golembiewski et al, 2015; Schmid et al, 2012; Ollikainen, 2014; Kirchen, 2012; Aguilar et al, 2013; EU SCAR, 2012; Schaltegger et al, 2013; Hadorn et al, 2006; Veldkamp et al, 2009	
1.6. Degree of cooperation between different actors in innovation development	Boehlje and Broring, 2011; McCormick and Kautto, 2013; Staffas et al, 2013; European Bioeconomy Panel, 2014	
1.7. Level of complexity in the policy framework	European Commission, 2012; Bigliardi and Galati, 2013; Philp et al, 2013	
1.8. Level of nonlinearity in the innovation development	Fetterhoff and Voelkel, 2006; Hadorn et al, 2006; Pohl, 2005 and 2008; Hermans et al, 2013; Berkhout et al, 2010; Gallagher et al, 2012; West and Bogers, 2014; Sandmeier et al, 2004	
2. Internal (organizational) variables		
2.1. Organizational culture	Brettel and Cleven, 2011; West and Bogers, 2014; Giannopoulou et al, 2011; Ollila and Elmquist, 2011; Chesbrough and Schwartz, 2007; Enkel et al, 2011; Salter et al, 2014)	Extent to which it supports innovation development
2.2. Organization's management and leadership	Giannopoulou et al, 2011; Herskovits et al, 2013; Nakagaki et al, 2012	Extent to which it supports innovation development
2.3. Configuration of the project team	Du et al, 2014; Frambach et al, 1998; Grote et al, 2012; Miller et al, 2007; Cooper et al, 1995	Extent to which it supports innovation development
2.4. Appropriation strategy	Huang et al, 2014; Laursen and Salter, 2013; Westergren and Holmstrom, 2012; Belderbos et al, 2013; Melese et al, 2009	Refers to practical uptake of innovation, and extent to which it supports innovation development
2.5. Organization's own resources and capacities	Frambach et al, 1998; Sisodiya et al, 2013; Cohen et al, 1990	Extent to which it supports innovation development
2.6. Ability to create and manage inter-organizational relationships	Sisodiya et al, 2013	Extent to which it supports innovation development
2.7. Total number of employees		General descriptor of organization, not directly linked to innovation
2.8. total annual revenue		In Euros. General descriptor of organization, not directly linked to innovation
3. External variables		
3.1. Policy makers	Ritter and Gemünden, 2004; Bigliardi and Galati, 2013; Peerlings et al, 2012; Golembiewski and Broring, 2015	Level of support to innovation development from a given actor group
3.2. Public authorities	Same as above.	Level of support to innovation development from a given

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		actor group. Referenced papers do not clearly discriminate between policy makers and public authorities
3.3. Competitors	Bigliardi et al, 2012; Laursen and Salter, 2013	Level of support to innovation development from a given actor group
3.4. Universities and research institutes	Boehlje and Broring, 2011; Golembiewski et al, 2015; Holl and Rama, 2012; Ritter and Gemünden, 2004	Level of support to innovation development from a given actor group
3.5. Suppliers	Bigliardi et al, 2012; Du et al, 2014; Ritter and Gemünden, 2004; Bigliardi and Galati, 2013	Level of support to innovation development from a given actor group
3.6. Other actors in value chain	Boehlje and Broring, 2011; Federal Ministry of Education and Research, 2011	Level of support to innovation development from a given actor group
3.7. Organizations from previously unrelated industries	Same as above	Level of support to innovation development from a given actor group
3.8. Users and customers	Du et al, 2014; Ritter and Gemünden, 2004; Bigliardi et al, 2012; Arnold and Barth, 2012; Hansen and Birkinshaw, 2007	Level of support to innovation development from a given actor group
3.9. Consultants	Ritter and Gemünden, 2004; Lichtenthaler, 2013; Almirall et al, 2014; Mina et al, 2013	Level of support to innovation development from a given actor group
3.10. Resource-based external support	Pride et al, 1991	Paper categorizes resources into following types: Financial resources (e.g. subsidies) Information Material resources Human resources Separate question was posed for each resource type
3.11. Usefulness of EU projects for innovation development		Added due to sample being based on EU projects
4. Outputs of innovation		
4.1. Total innovation expenditures	Kleinknecht et al, 2002; Edison et al, 2013	
4.2. Number of patents and patent applications	Same as above	
4.3. Revenue stemming from the innovation	Same as above	
4.4. Number of new product or service announcements	Same as above	
4.5. Judgment on how successful was the innovation development		

Questions on type, stage of development and TRL of innovation have categorical answer options (e.g. is the innovation a product or a service, or is it in idea generation or implementation phase). All other questions are posed with ordinal scale of answers, where five-point Likert scale is used for all questions except the question on the success-level of the innovation (nine-point Likert scale). The questionnaire was pre-tested with researchers, and based on their feedback, the questionnaire wording was revised.

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A total of 387 projects (FP7, H2020 and different ERA-NETs) have been identified as relevant for this study, with a total of 1063 private companies participating. Given that some of the companies have participated in several projects (total 1333 project participations), the questionnaire was sent individually for each project participation, and separately to different employees that have worked on these projects. As the sampling frame was linked to the data set developed in the first mapping of research activity, it was possible to establish a clear link of a given project participation to the name and the funding allocated to that project, as well as the topic of the project.

The sampling frame was decreased from 1333 to 1265 project participations, as not all companies had valid email contacts (we disregarded the ones where the email domain or address was not active). The questionnaire was designed on an interactive SurveyMonkey on-line platform. The invitation to participate to the survey was sent via email to the respective addresses, along with a short description of the study, anonymization of responses and a unique user-id code that allows to link individual response to the project data base. The first round of emails was sent on 6th of September 2017 and has resulted with 79 responses, while reminder emails were sent of 29th of September and have resulted with 93 responses. Only individual responses that have inserted appropriate used-id code have been treated as valid, which decreased the total number of responses to 145. These valid respondents have answered on 84.72% of questions. The innovations that were the object of inquiry are the innovations that were developed within the respective FP7, H2020 and ERA-NET projects, and not on the overall innovations developed in that organization. The questionnaire was answered by people from the targeted organizations that have worked on the sampled projects and are familiar with the innovation case. Examples of the sampled innovation cases from different types of innovation, different stages of development and in different supply-chain groups are presented in the Table 3.

Table 3. Innovation examples

No.	1.	2.	3.	4.
Innovation	OPERAs Global Exemplar https://operas-global.ourecosystem.com	Development of next-generation forwarder	Development of business model for new type of jet fuel	Improved hybrid separation and extraction of hemicellulose
Company	ECO-METRICA LIMITED	HSM HohenloherSpezial-Maschinenbau GmbH & Co. KG	SKYENERGY BV	Cursor Oy
Country	United Kingdom	Germany	Netherlands	Finland
Project	Operational Potential of Ecosystem Research Applications	Smart Forwarder for sustainable and efficient forest operation and management	Production of fully synthetic paraffinic jet fuel from wood and other biomass	Controlled separation and conversion processes for wood hemicelluloses
Topic	1.3.Forest ecosystem services	2.1.Forest management	3.4.Bioenergy	4.8.Downstream processing
Innovation type	Service	Good	Business practice / models	Production method
Stage	Initiation of adoption	Design and development	Problem-solving (includes defining of	Technology demonstration

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			economic feasibility)	for specific application
Year started	2012	2016	2015	2013

4. RESULTS

4.1 Mapping forest bioeconomy research capacities

Overall, capacities in forest bioeconomy increase along the supply chain, from Forest systems (122.5 – i.e. sum of all normalized organizational capacities in this category), across Forest biomass & raw materials (120.23), to Primary processing (210.43) and Secondary processing (204.6). As presented on Figure 3, total research capacities increase from Southern, across Eastern and Northern to Western Europe.

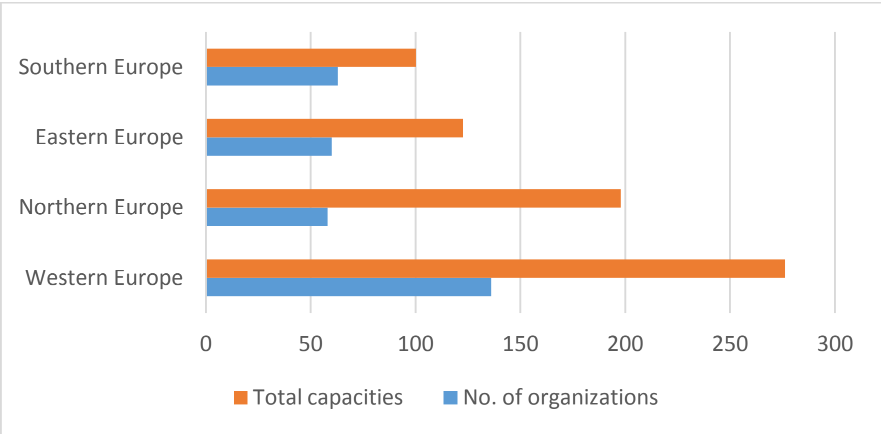

Figure 3. Number of organizations and capacities by region

Figure 3 presents the overall distribution of organisations and capacities. It is evident that Western Europe hosts the highest number of organisations and thus it is not surprising it has the strongest capacities. On the other hand, the rest of the regions have a similar number of organisations, but rather big differences in capacities. For example, the number of organizations in Northern Europe is not much smaller than in Eastern (60) and Southern Europe (63), but the overall capacity is much higher. The ratio between capacities and the number of organizations in Northern Europe is 3.4, compared to 2.0 (Eastern Europe) and 1.6 (Southern Europe).

When these regional capacities are broken-down to the four supply-chain categories (Figure 4), it can be seen that each European region has sizable capacities in each supply-chain category.

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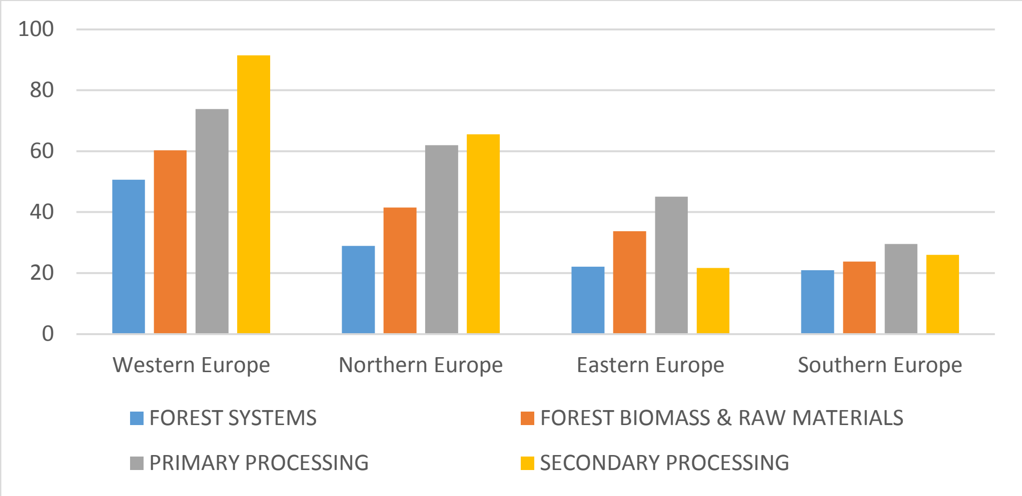

Figure 4. Regional research capacities by supply-chain category

Figure 4 also shows that both Eastern and Southern Europe have highest capacities in primary processing, while Western and Northern Europe have highest capacities in secondary processing. Although total capacities increase along the categories of the supply chain (Figure 3), depiction of capacities by individual topics within those categories (Figure 5) shows that capacities by topic greatly vary, where they are most pronounced in Pretreatment technologies (topic 3.2), followed by Forest inventory and economics (1.1), Forest management (2.1), Wood processing (3.1) and Biopolymer processing (4.4).

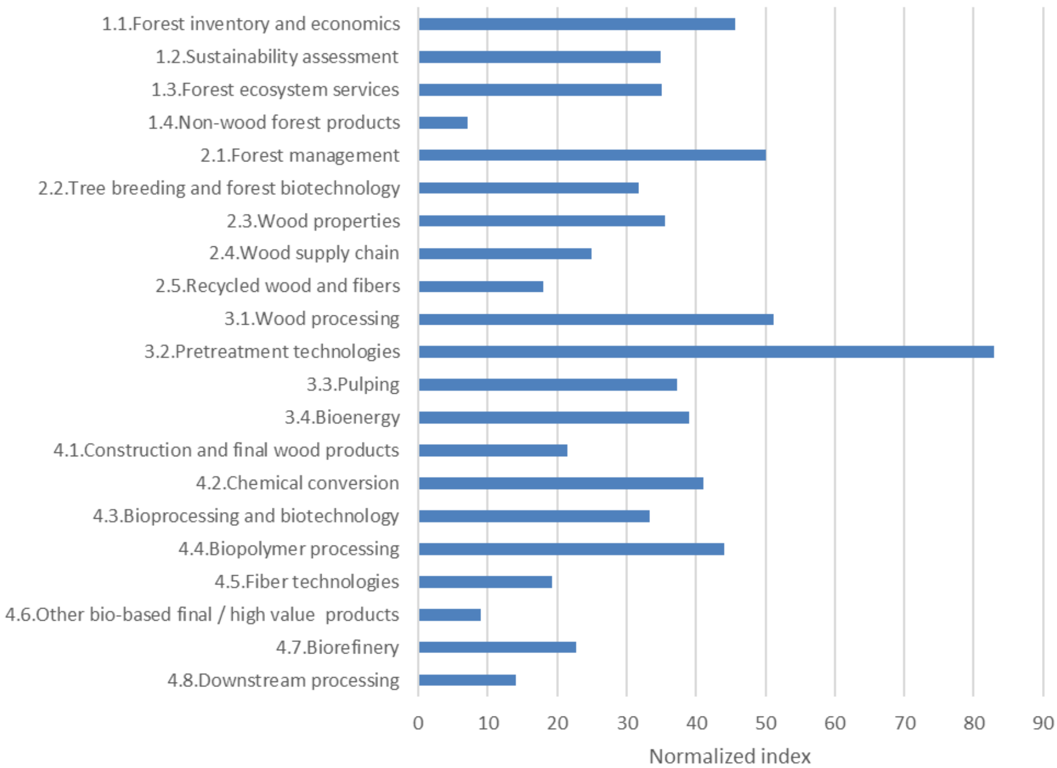

Figure 5. Total capacity by topic

When country-level research capacities are reviewed (Figure 6), it can be seen that this distribution is highly uneven. Sweden, Germany, Finland, France and Spain together account for 49% of total

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mapped research capacities. Although in general countries have capacities in all categories of the supply chain, from the leading countries Germany has relatively low capacity in Primary processing and Italy has relatively low capacity in Secondary processing.

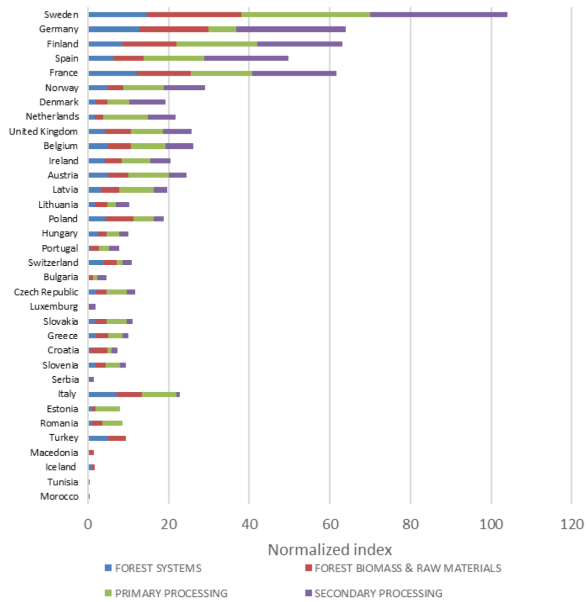

Figure 6. Country-level capacities by category

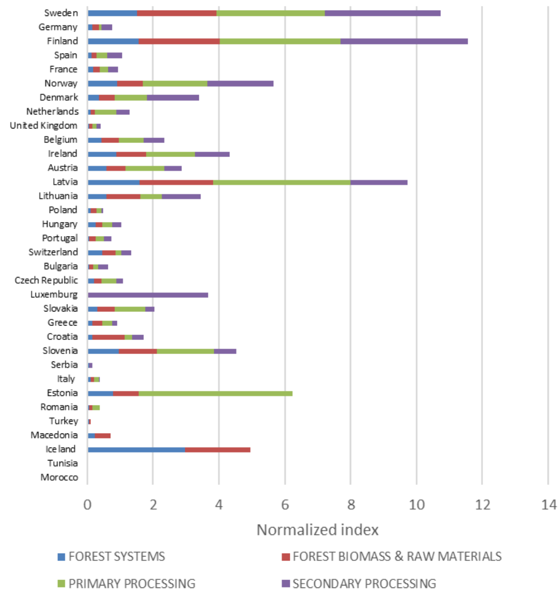

Figure 7. Capacity by population and category

Comparison of research capacities by country in the field of forest-bioeconomy should be done with some reserve, as it does not take into consideration differences in characteristics (e.g., population size, forest-sector importance) between individual countries. For example, by dividing total capacities by country's population (in millions, Figure 7), by total forest area (in millions of ha, Figure 8), and by total removals (in millions m^3, Figure 9; all based on State of Europe's Forests 2015), we obtain a very different image of capacities.

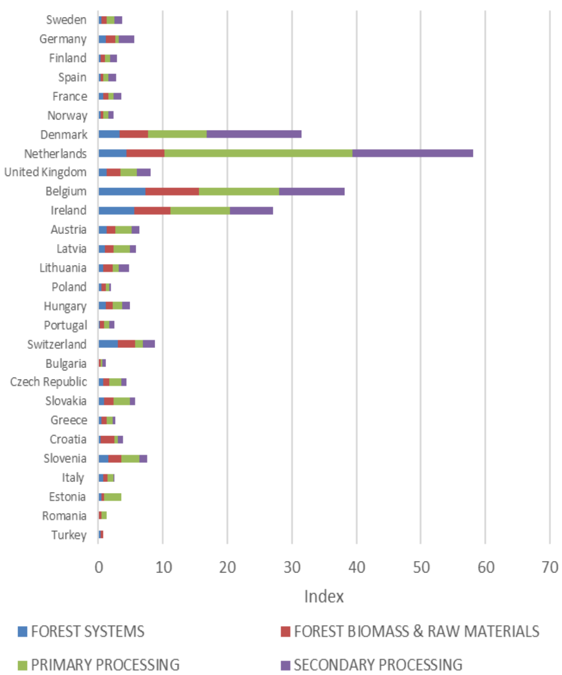

Figure 8. Capacity by country and forest area

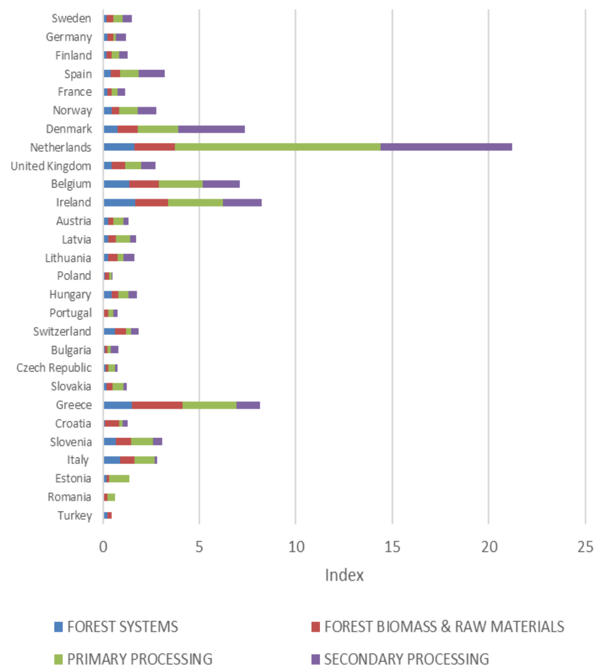

Figure 9. Capacity by country and removals

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When total capacities are normalized by population size (i.e. divided by population in millions), it can be seen that several countries with low population density (Sweden, Finland, Norway and Latvia) present peaks in the distribution, while highly populated countries with high overall capacities (Germany, France and Spain) are at the lower ends of distribution. Cross-country comparison looks again different when capacities are normalized by forest area (Figure 8) and removals (Figure 9), where countries with low forest coverage such as Netherlands, Belgium, Denmark and Ireland dominate the distribution. From the top ten organizations with the highest cumulative research capacities in the field of forest bioeconomy (Figure 10), seven are located in the Nordic countries.

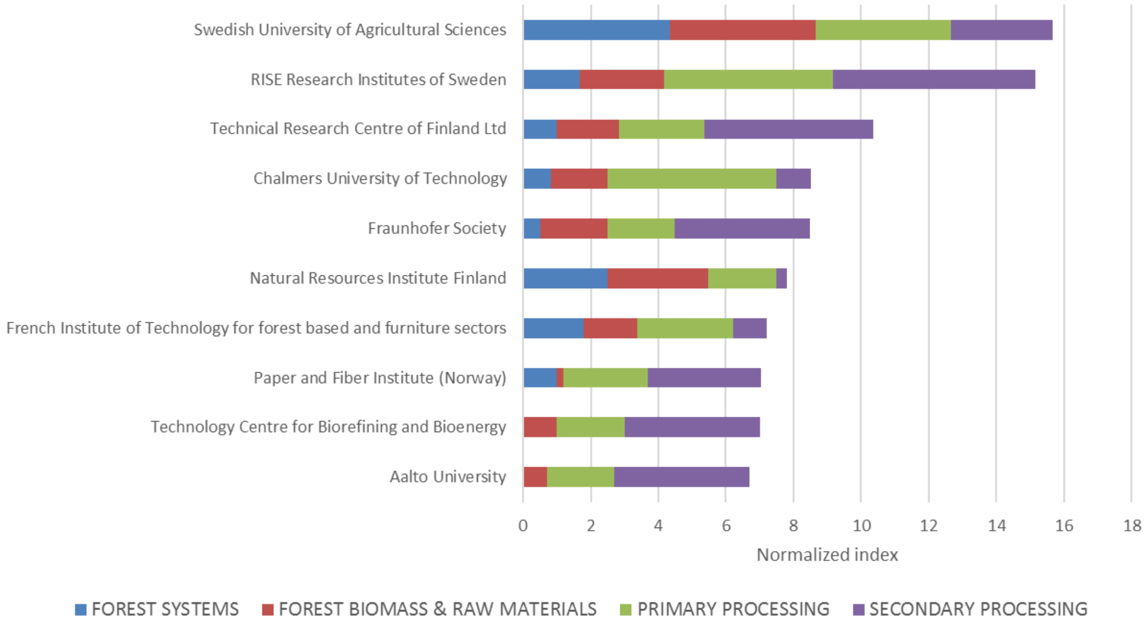

Figure 10. Total capacity of top 10 organizations

Most of these top organizations have capacities in all categories of the supply chain. With the exception of SLU (Swedish University of Agricultural Sciences) and LUKE (Natural Resources Institute Finland), all other top organizations have more capacities in primary and secondary processing than in the first two categories of the supply chain classification. Additional results from capacity mapping are presented in Appendix II.

4.2. Mapping forest bioeconomy research activity

In total 387 projects have been identified as “forest bioeconomy research”, with 1978 participants from 66 countries, and an overall value of 1.4 billion Euros. Figure 11 shows the development in funding and number of projects. In 2006 only ERA-NET (i.e. WOODWISDOM) projects began, while FP7 projects started in the 2007-2015 period, and the H2020 projects started in the 2014-2017 period. Three FP7 projects started in 2015 and two H2020 projects started in 2014.

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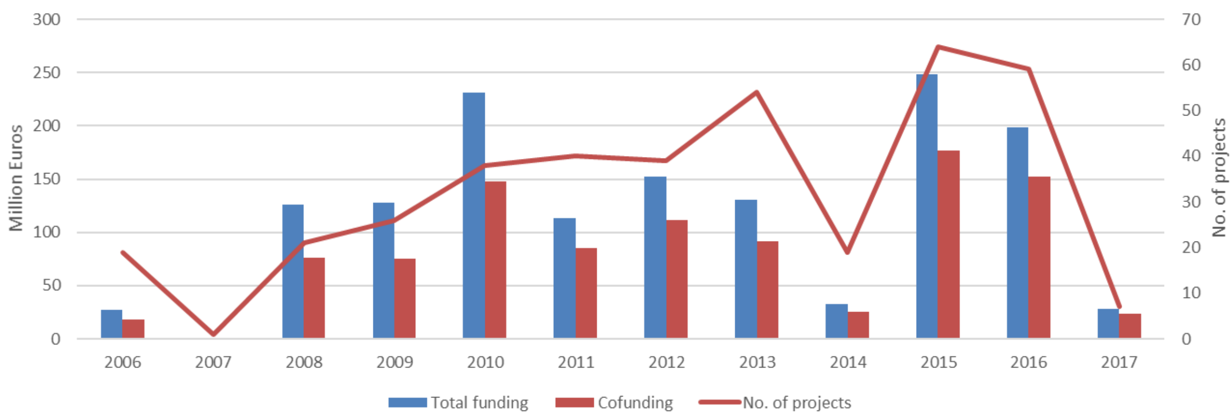

Figure 11. Financing of research activities by year

An overall trend can be seen of increase in annual funding, and that beginning and ending years of a framework programme have smaller numbers of started projects. Average EC funding rate (i.e. share of EC's co-funding) increased from the 2008-2014 period (67.1%) to the 2015-2017 period (74.2%), where the average EC funding rate of the entire observed period was 69.8%.

Figure 12. Annual total funding and number of projects by time period

Similar to the increase of capacities along the supply chain, the total annual funding also increased along the supply chain categories, with the greatest increase in the two middle categories of the supply chain (Figure 12). The number of projects during FP7 was smaller in primary processing than in other categories, whereas in H2020 the number of projects is very similar across all supply chain categories. Comparing funding and number of projects, it can be stated that on average projects tend to increase in funding along the supply chain.

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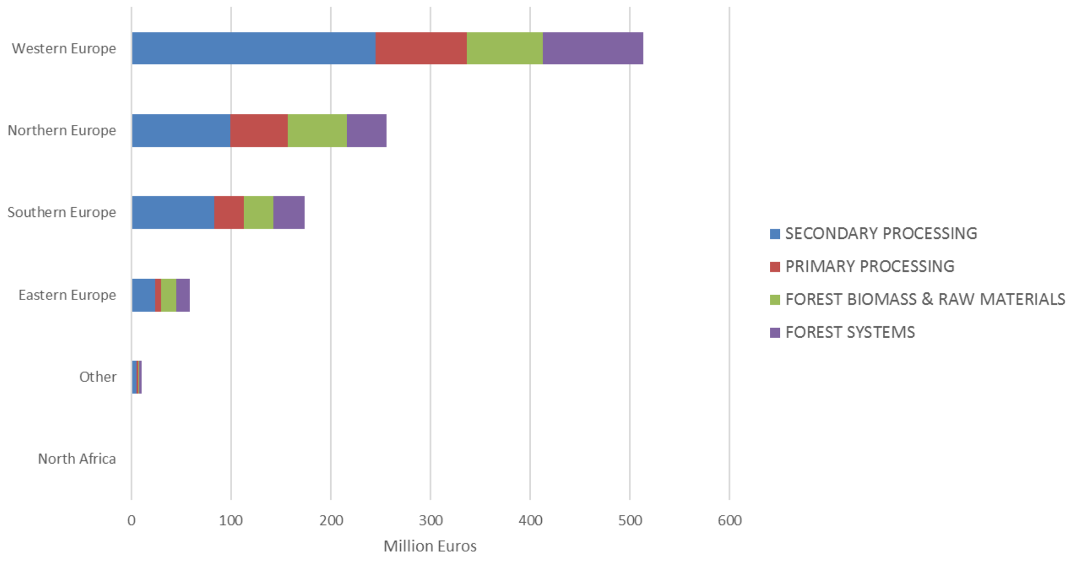

Figure 13. EC's funding by region and category

Level of EC funding decreases from Western, across Northern and Southern, to Eastern Europe (Figure 13). Similar to regional distribution of capacities, each region has capacities in each section of the supply chain, while secondary processing is the category with highest EC funding.

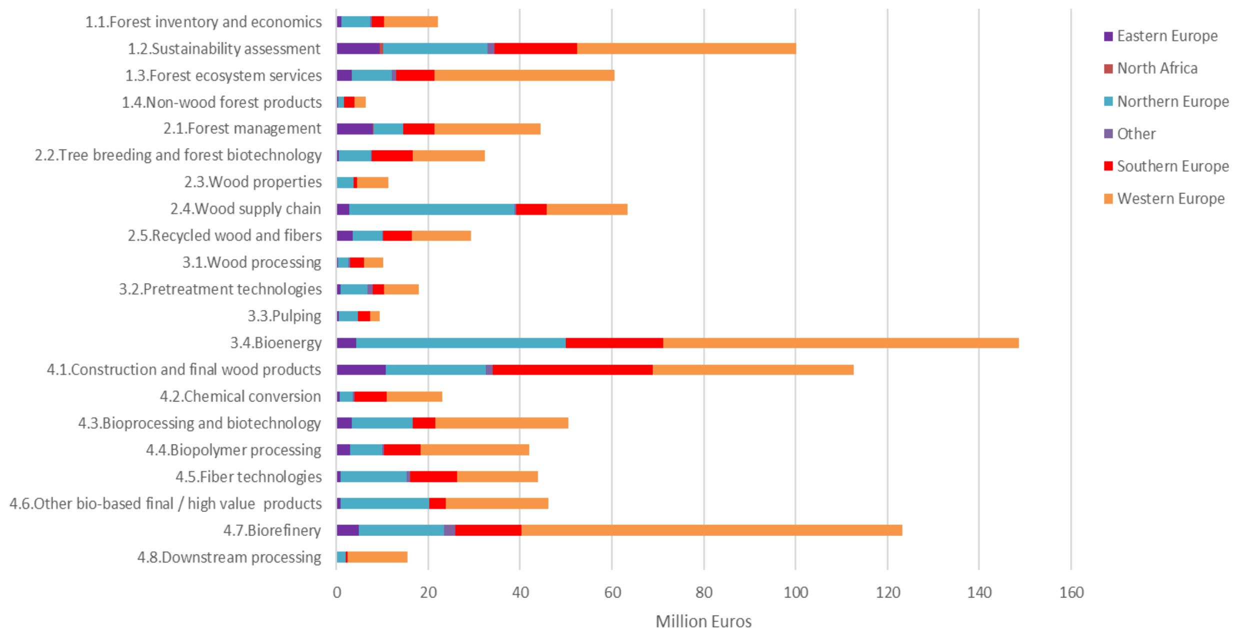

Figure 14. EC's funding by region and topic

The distribution of EC funding by topics (Figure 14) is very uneven. Bioenergy (3.4), Biorefinery (4.7), Construction and final wood products (4.1) and Sustainability assessment (1.2) have received more than one hundred million of Euros each. It is also noticeable that on average, the share of EC funding in Western European countries for these topics is higher than for other topics.

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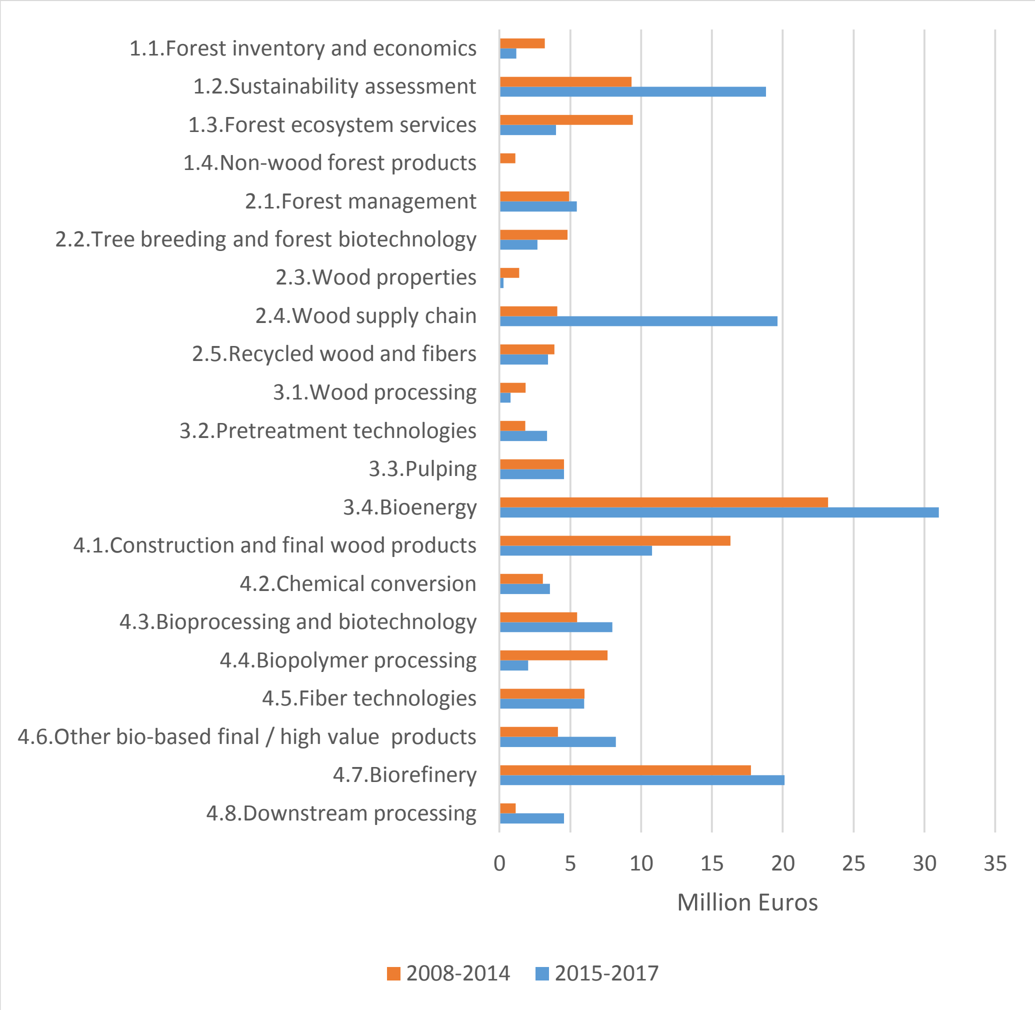

Figure 15. Change in average annual total funding over time

When average annual project funding is split for periods that correspond to FP7 (2008-2014) and H2020 (2015-2017), it can be seen (Figure 15) that the funding was not stable for majority of topics throughout the observed period. The topics for which the funding has substantially increased in H2020 are Sustainability assessment (1.2), Wood supply chain (2.4) and Downstream processing (4.8), while the topics for which the funding has substantially decreased in H2020 are Forest inventory and economics (1.1), Forest ecosystem services (1.3), Non-wood forest products (1.4), and Wood properties (2.3).

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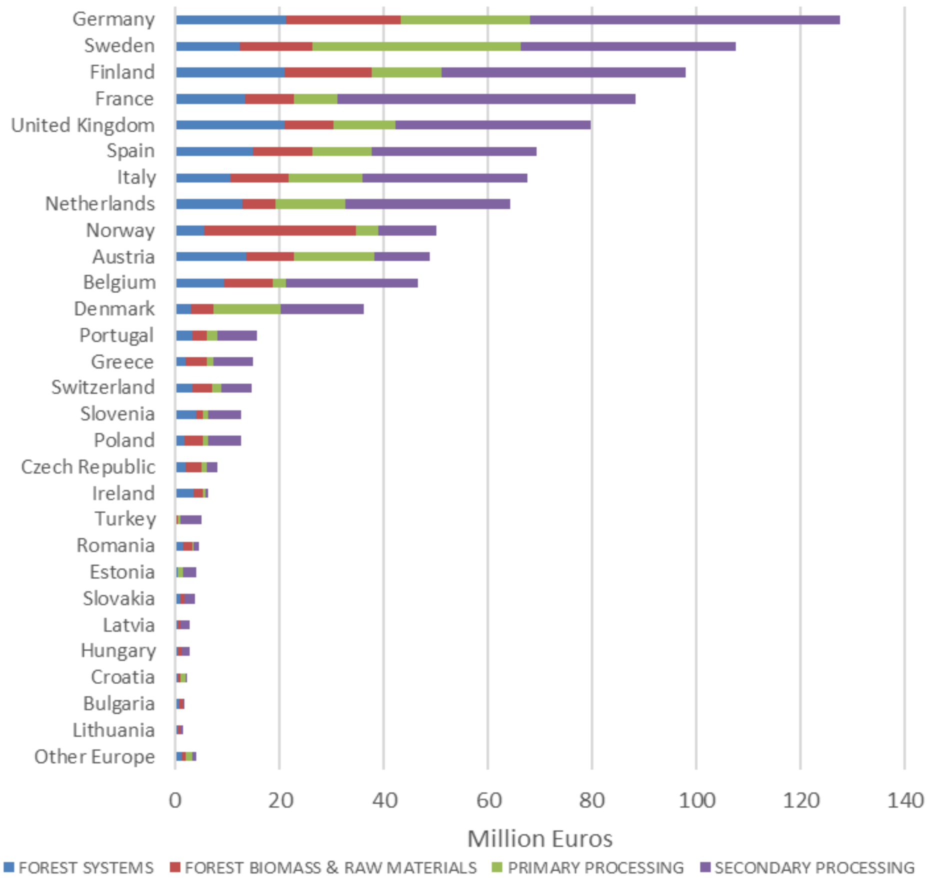
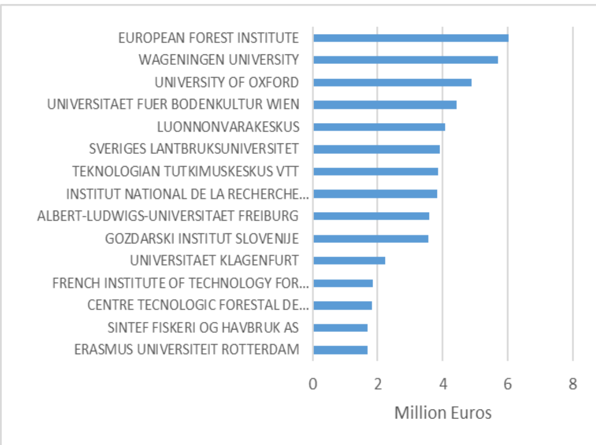


Figure 16. EC's funding by country and category

When EC funding is aggregated by country level (Figure 16), Germany is at the top (128 mil. €), followed by Sweden (108 mil. €), Finland (98 mil. €) and France (88 mil. €). For normalization (i.e. dividing the funding by a given criteria) of national funding by population, forest area and removals see Appendix III.



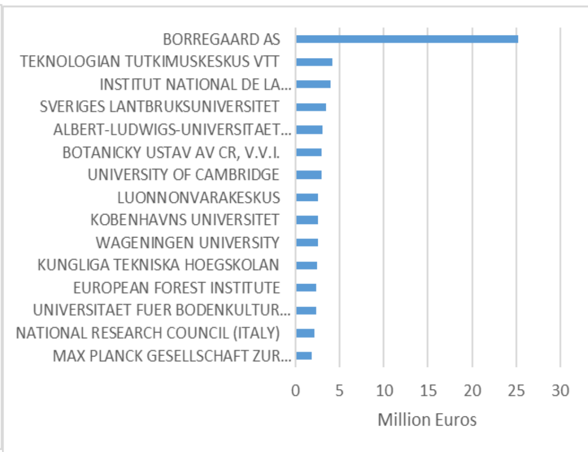


Figure 17. EC's funding in Forest systems Figure 18. EC's funding in Forest biomass & raw materials

The distribution of EC funding by top 15 organizations in each of the four categories is shown in Figures 17-20. In the Forest systems category the top 15 organizations come from the public sector. Although several organizations have received higher levels of EC funding (e.g., European Forest

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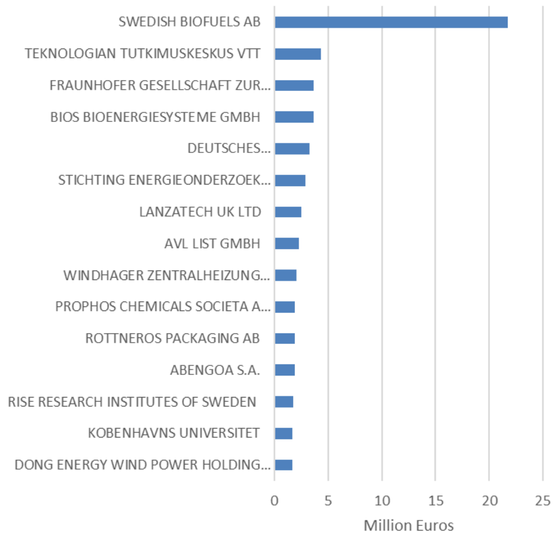
Institute,Wageningen University), the distribution is rather balanced. Similar distribution can be found in the second stage of the supply chain (Figure 18- Forest biomass & raw materials), but with one important outlier – Borregaard, a Norwegian company that is on the top of the distribution (25.2 mil. € of EC's funding). This is mostly attributed to their coordination of the EXILVA (Flagship demonstration of an integrated plant towards large scale supply and market assessment of microfibrillated cellulose) project.



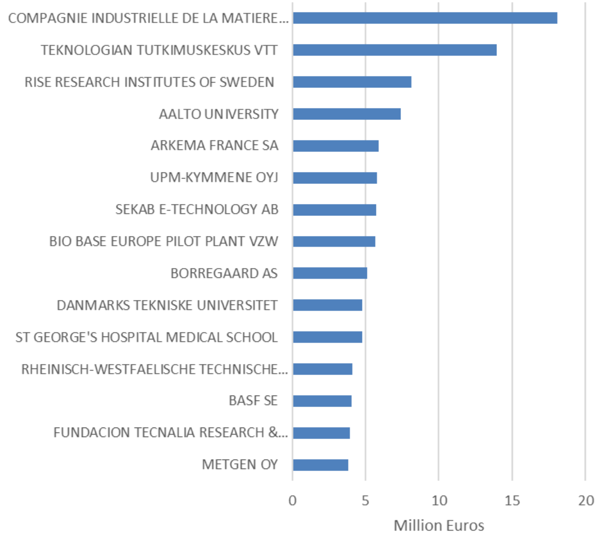


Figure 19. EC's funding in Primary processing

Figure 20. EC's funding in Secondary processing

The domination of a single private company at the top of rather uniform funding distribution is again present in Primary and Secondary processing (Figures 19 and 20). Overall share of EC funding allocated to private companies is highest in Primary processing (85%), where Swedish biofuels AB received highest level of EC's funding (21.7 mil. €), followed by Technical Research Centre of Finland (VTT – 4.3 mil. €) and Fraunhofer Society (3.6 mil. €). The co-funding in Secondary processing is more balanced, with private companies receiving 35% of the overall funds. CVIM (Compagnie Industrielle de la Matière Végétale) has received highest level of EC's funding (18.1 mil. €), mostly due to their role as coordinators of the 2G BIOPIC (Second Generation Bioethanol sustainable production based on Organosolv Process at atmospheric Conditions), which focuses on a second-generation demonstration plant for the production of bioethanol from agricultural residues and wood.

To describe collaboration between individual organizations and countries, organization-by-organization matrices have been constructed for each of the four categories of the supply chain, where values in the matrices represent number of project collaborations between two organizations. Country-by-country matrices of collaboration have been constructed by aggregation of organization-by-organization matrices. Layout of graphs based on country-level matrices is set by latitude and longitude of individual countries. Layout of graphs depicting cooperation between organizations is such that those organizations which frequently cooperate with one another are placed close to each other, while centre of the graph is reserved for organizations which most frequently cooperate with many other organizations. Private organizations are marked with magenta circles, while all other organizations and countries are marked with blue squares. Size of the country's and organizational label as well as it symbols reflect the level of received EC's funding. In all visualizations except the ones that show entire inter-organizational networks, the collaboration ties are scaled both in width and colour according to the frequency of collaboration. The graphs for

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first supply chain category (Forest systems) are presented in Figure 21 (all other categories are presented in Appendix III).

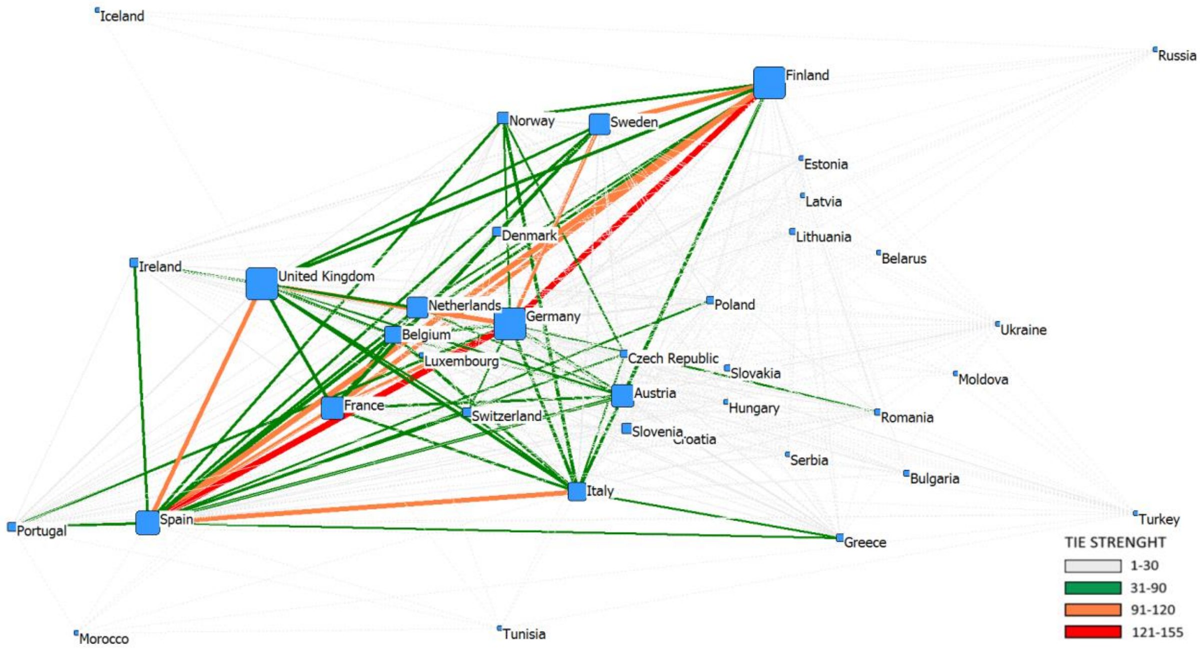

Figure 21. Collaboration between countries in Forest systems

Figure 21 shows that in the context of Forest systems category, most frequent collaboration has occurred between Germany and Finland (131 project collaborations) and between Germany and Spain (155 project collaborations). These strongest collaboration ties are followed by group of second-highest frequencies of collaboration that are between Finland on one side and Sweden (98), Spain (119) and France (102) on another, but also Spanish ties with Italy (112) and UK (102) and the collaboration between France and Germany (95). It can also be seen that there are very few collaboration ties with Eastern European countries; and this feature is present throughout all supply chain categories.

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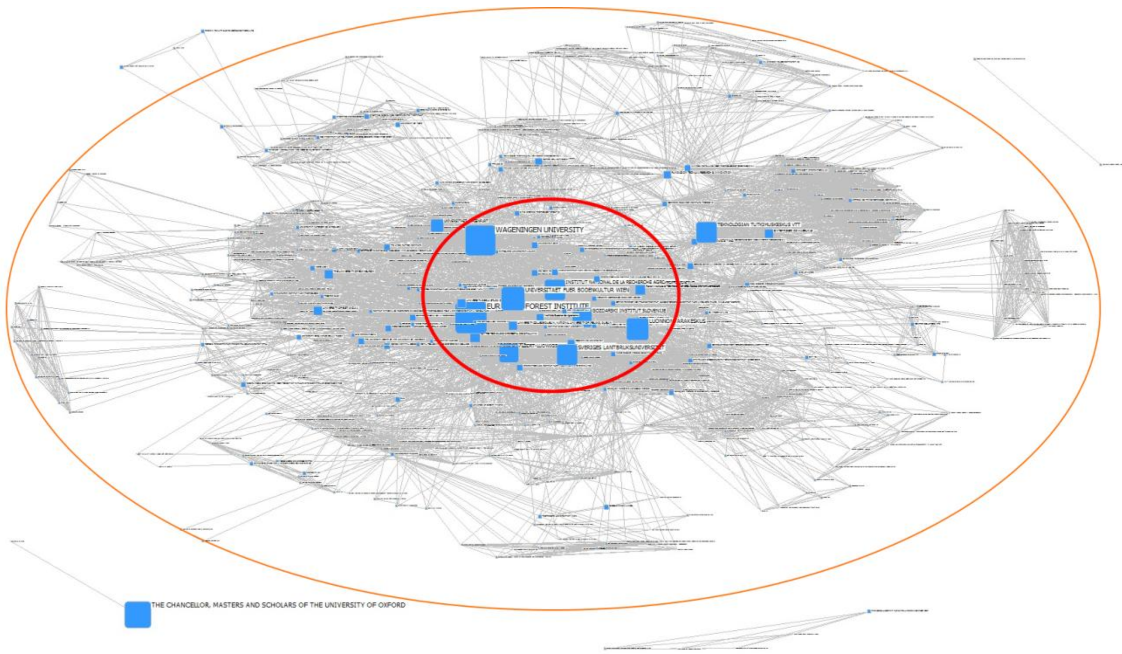

Figure 22. Collaborations between organizations in Forest systems

The vast majority of collaboration between organizations (Figure 22) form a single cluster of organisations (indicated with orange ellipse), meaning that, directly or indirectly, almost all sampled organizations have cooperated on the topic of Forest Systems. The only organization that has received substantial EC's funding and is isolated from the prevailing group is the University of Oxford due to their participation in the GEM-TRAIT (The Global Ecosystems Monitoring and Trait Study: a novel approach to quantifying the role of biodiversity in the functioning and future of tropical forests) project which is focused on tropical forests. It can also be seen that the centre of Figure 22 is occupied by a large number of organizations that have received substantial amounts of funding, and have frequently collaborated with one another (indicated with red ellipse). That part of the inter-organizational collaboration network is presented by Figure 23.

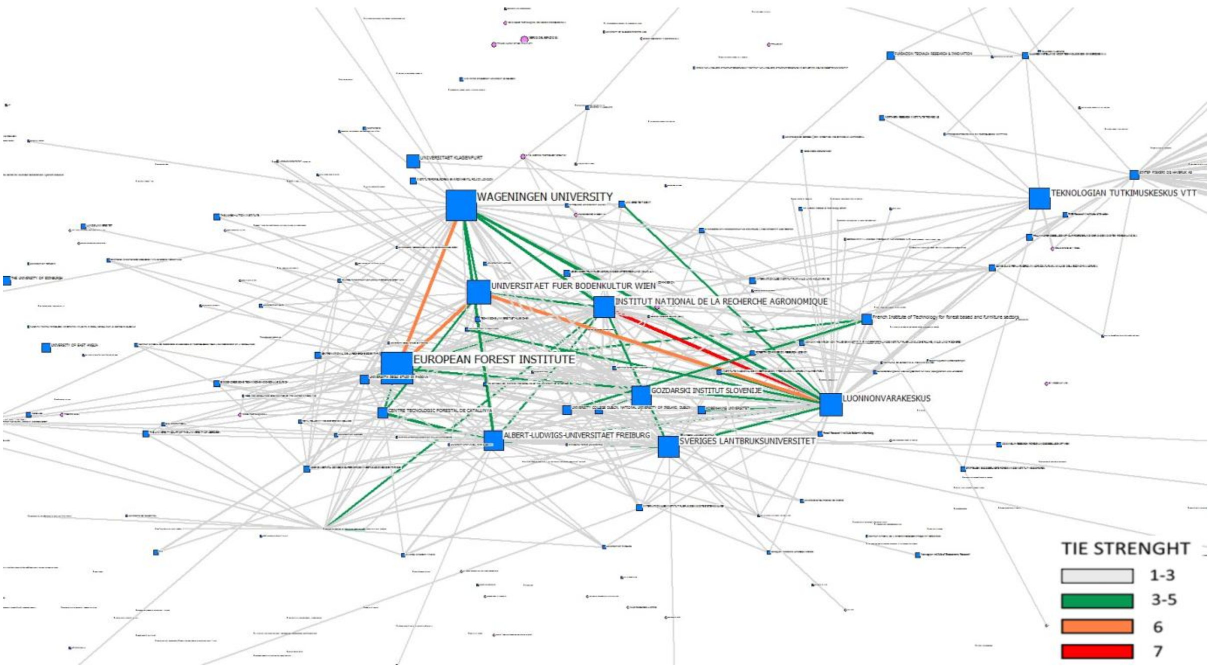

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Figure 23. Collaboration between central organizations in Forest systems

It can be seen that the pairs of organisations that have most established collaborations are INRA (Institut national de la recherché agronomique - National Institute of Agricultural Research) and LUKE (Luonnonvarakeskus - Natural Resources Institute Finland); BOKU (Universität für Bodenkultur Wien - University of Natural Resources and Life Sciences, Vienna) and LUKE; and European Forest Institute and Wageningen University. It can also be seen that VTT has a unique position, as it is the only organization in main component that has received substantial EC's funding, and has not frequently collaborated with any of the other prominent organizations, but has rather established its own 'cloud' of collaborating organizations. Such kind of analysis has been performed on all four supply-chain categories. The summary results are presented in Table 4 (all other visualizations are in Appendix III).

Table 4. Summary of collaborations between countries and organizations

CATEGORY	TYPE OF NETWORK	PRIMARY TIES (largest number of collaborations)	SECONDARY TIES (second-largest number of collaborations)
1.FOREST SYSTEMS	Countries	Germany to Finland and Spain	Finland-Sweden; Finland-Spain; Sweden-Germany; Finland-France; Spain-Italy; Spain-UK
	Organizations	INRA-LUKE	EFI-WAU; EFI-BOKU; BOKU-LUKE
2. FOREST BIOMASS & RAW MATERIALS	Countries	Germany to Finland	Finland-Italy; Finland-Sweden; Sweden-Germany; Germany-Austria; Germany-Italy; Spain-France; France-Germany; Spain-Finland
	Organizations	NRC-INRA; NRC-LUKE	EFI-UNF; UNF-BOKU
3. PRIMARY PROCESSING	Countries	Germany-Austria	Germany-Spain; Netherlands-Finland
	Organizations	VTT-SLU	non academic
4. SECONDARY PROCESSING	Countries	Germany-Finland; Germany-Netherlands; Germany-France	Italy-UK-France-Sweden; Finland-France; Netherlands-France; Belgium-France
	Organizations	VTT-UNIHEL; VTT-RISE; RISE-FCBA	VTT-Aalto; VTT-FRAUNHOFER; VTT-LUND; LUND-RISE

On country level, in all four categories of the supply-chain classification Germany, Finland and France are in the centre, followed by Italy, UK, Sweden, Netherlands and Spain. Same cannot be stated for inter-organizational collaboration networks, as they differ among themselves. The role of established forestry research organizations is minor in primary and secondary processing. VTT with

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its own small, partially separated collaboration network in Forest systems has come to dominate the collaboration network in later stages of the supply chain. Collaboration networks in Primary processing differs from all others, as it is fragmented into ten groups of organizations with no collaborations between them (see Appendix III). This network is also highly dominated by private companies, and the only collaboration between research organizations that stands out is the one between VTT and SLU.

4.3. Comparison of research capacities and research activity

The final step of the analysis is the comparison between research capacities and research activities in EC's framework programmes. Topic-specific comparison between the two is presented by Figure 24, where both capacities and research EC's funding has been scaled from 0 to 1 (capacity by topic has been divided by maximum capacity attributed to a single topic, and funding by topic has been divided by the maximum funding allocated to a single topic). Funds and capacities of private companies have not been included in the analysis.

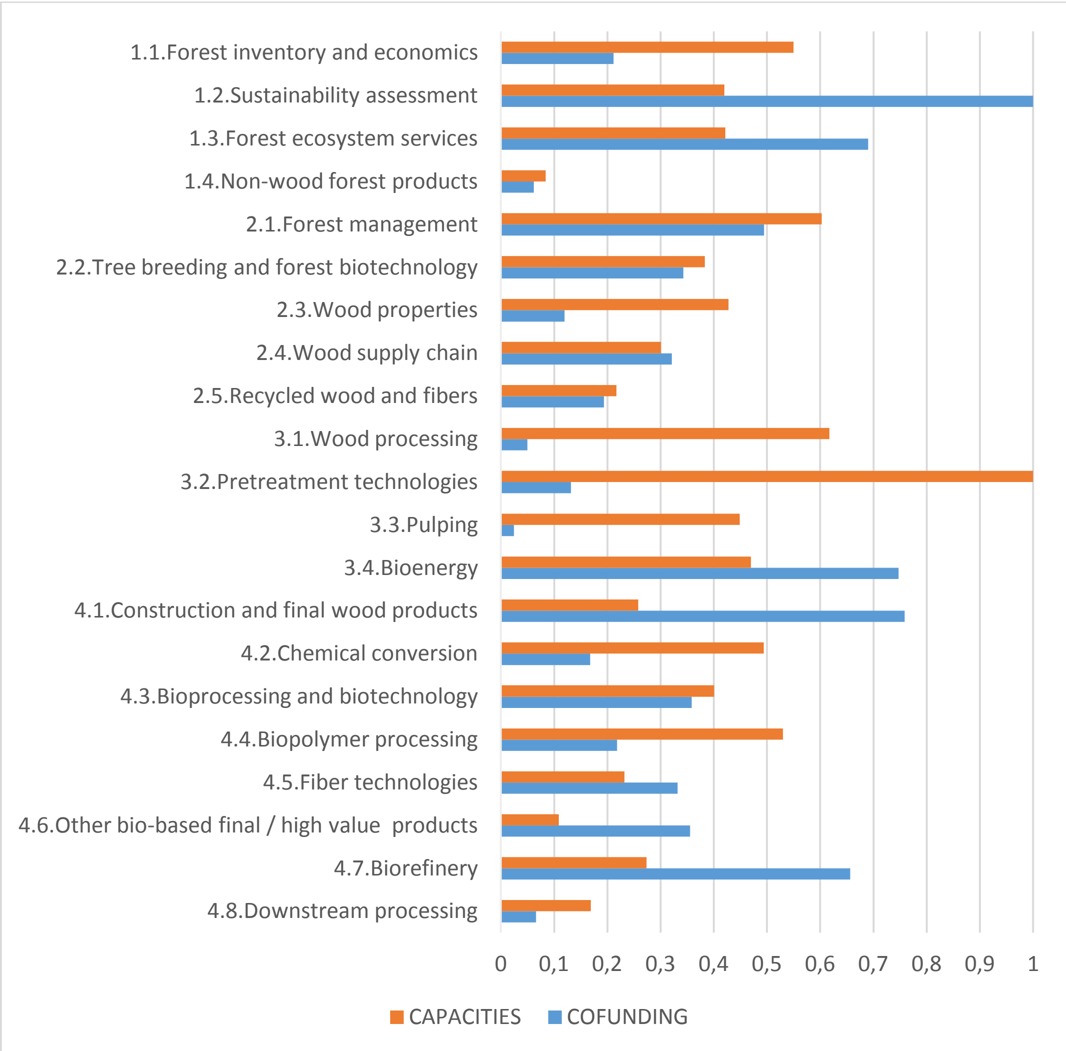

Figure 24. Comparison of research capacities and EC's funding by topic

It can be seen that both distributions of research capacities and EC's funding are very uneven, and that the same can be stated on the ratio between the two for individual topics. Highest overall topic-

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specific EC funding over the whole observed period is allocated to the Sustainability assessment topic (1.2), while highest research capacities are present in Pretreatment technologies (3.2). Topics that have significantly more funding than research capacities are: Sustainability assessment (1.2), Forest ecosystem services (1.3), Bioenergy (3.4), Construction and final wood products (4.1), Other bio-based / high value products (4.6) and Biorefinery (4.7). Topics that have significantly less funding than research capacities are Forest inventory and economics (1.1), Wood properties (2.3), Wood processing (3.1), Pretreatment technologies (3.2), Pulping (3.3), Chemical conversion (4.2), Biopolymer processing (4.4) and Downstream processing (4.8).

A comparison of research capacities and EC's funding by region is presented in Figure 25.

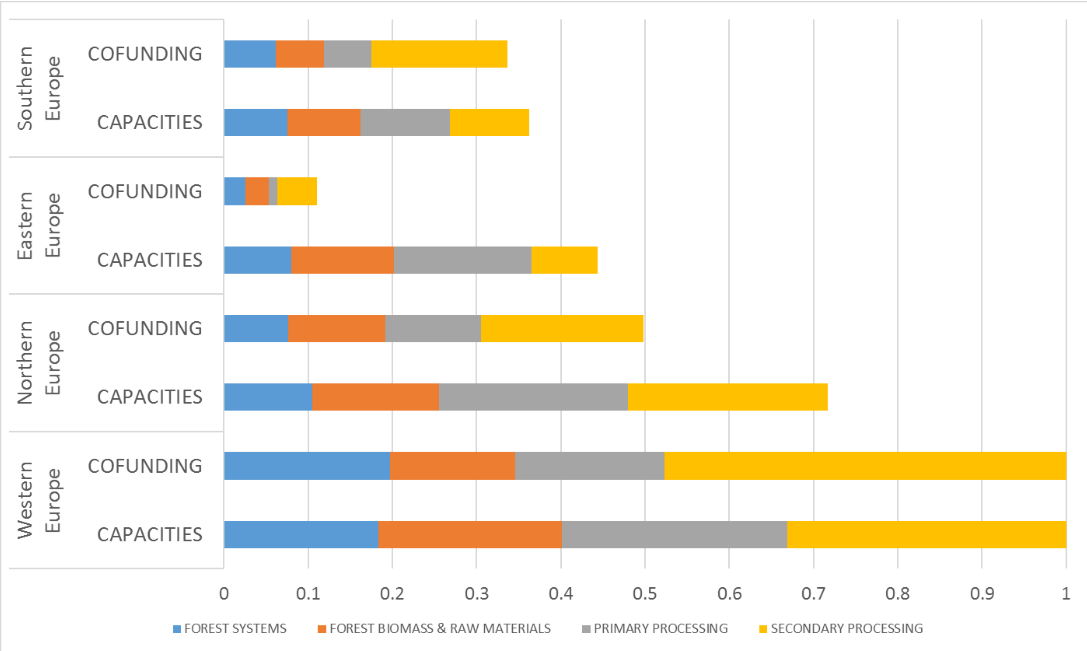

Figure 25. Comparison of research capacities and EC's funding by region

Southern and Western Europe have balanced research capacities and funding. Northern Europe has a 'surplus' of capacities. Striking is the very low level of EC's funding in Eastern European countries in view of the capacities there. The ratio of capacities and EC funding by individual supply chain categories is somewhat balanced, with exceptions of Southern Europe's low EC's funding in Primary processing, and Eastern Europe's low EC's funding in Forest biomass and raw materials and Primary processing. Additional results from research activity mapping are presented in Appendix III.

4.4. Participation of private companies in forest bioeconomy research and innovation projects

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Before reviewing the results of the innovation survey, we present the descriptive information for participation of private companies in the totality of sampled projects; starting with their participation by country (Figure 26). Non-EU countries that have received EC's co-funding (such as Israel) are also listed in the results.

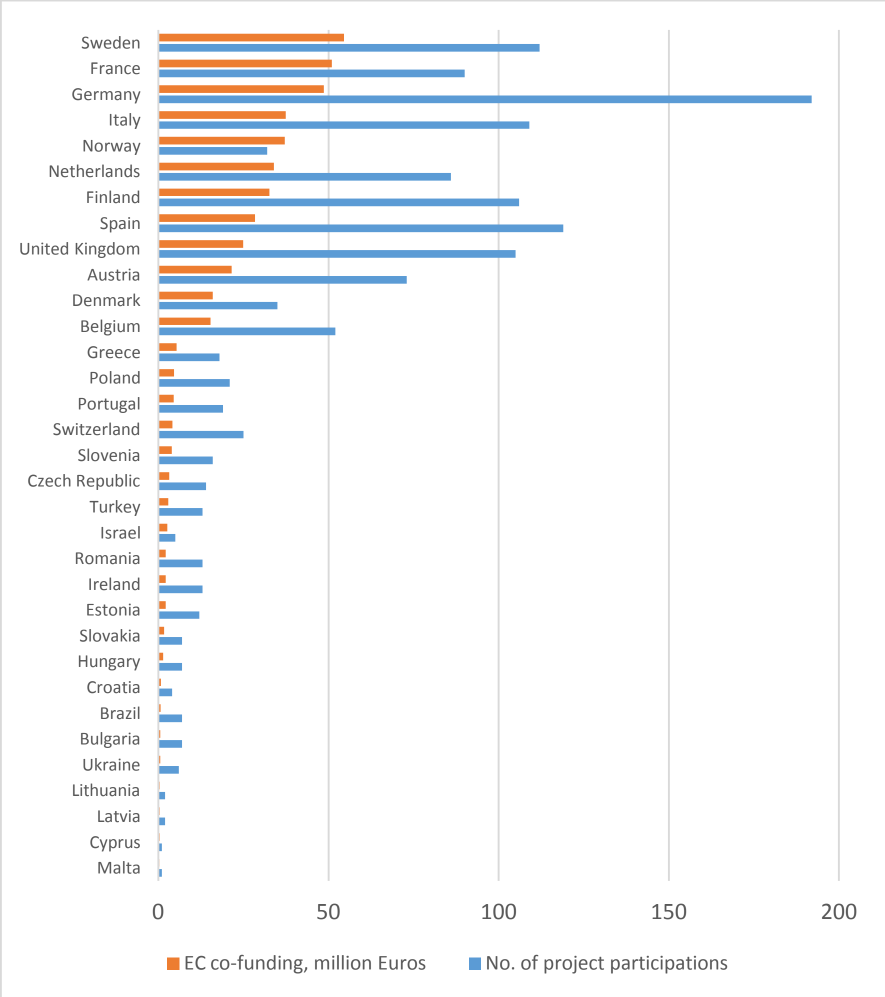

Figure 26. Number of project participations and EC's co-funding (mil. Euros) for private companies

In terms of total EC's co-funding per country, Sweden (55 mil. Euros) and France (51 mil. Euros) are at the top of the list. The leader-scale of countries in terms of project participations is somewhat different, as German (192) and Spanish (119) have participated most frequently in the sampled projects. However, in general it can be stated that the activity of private companies diminishes from North-Western to South-Eastern Europe, same as is the case with the overall sample of all types of organizations.

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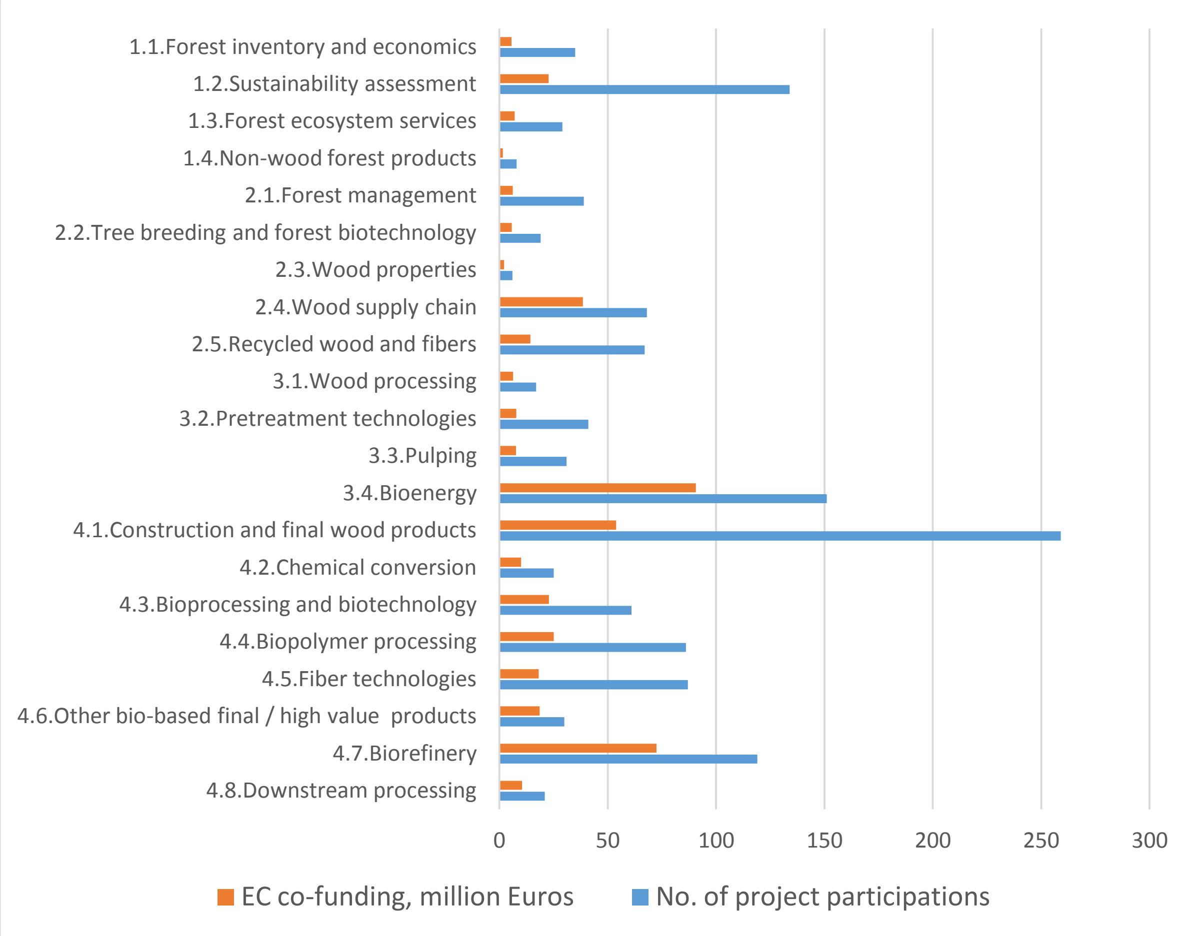

Figure 27. EC's co-funding and number of project participations of private companies by topic

The activity of private companies distributed across topics in the supply-chain categorization (Figure 27) increases along the supply chain, with Bioenergy (91 mil Euros) and Biorefineries topic (72 mil. Euros) receiving largest amounts of EC's co-funding. The average EC'c co-funding per project participation for private companies was 335 495 Euros. The average EC'c co-funding per project participation grows in each supply chain category, as it is 190 791 Euros for 1.Forest systems, 317 345 Euros for 2. Forest biomass & raw materials, 352 163 Euros for 3. Primary processing and 400 084 for 4.Secondary processing. From individual topics, it is largest for 4.6.Other bio-based final / high value products (predominantly pharmaceuticals; 619 077 Euros), 4.7.Biorefinery (609 080 Euros) and 3.4.Bioenergy (600 261 Euros), while it is smallest for 2.1.Forest management (156 889 Euros), 1.1.Forest inventory and economics (160 573 Euros) and 1.2.Sustainability assessment (168 950 Euros).

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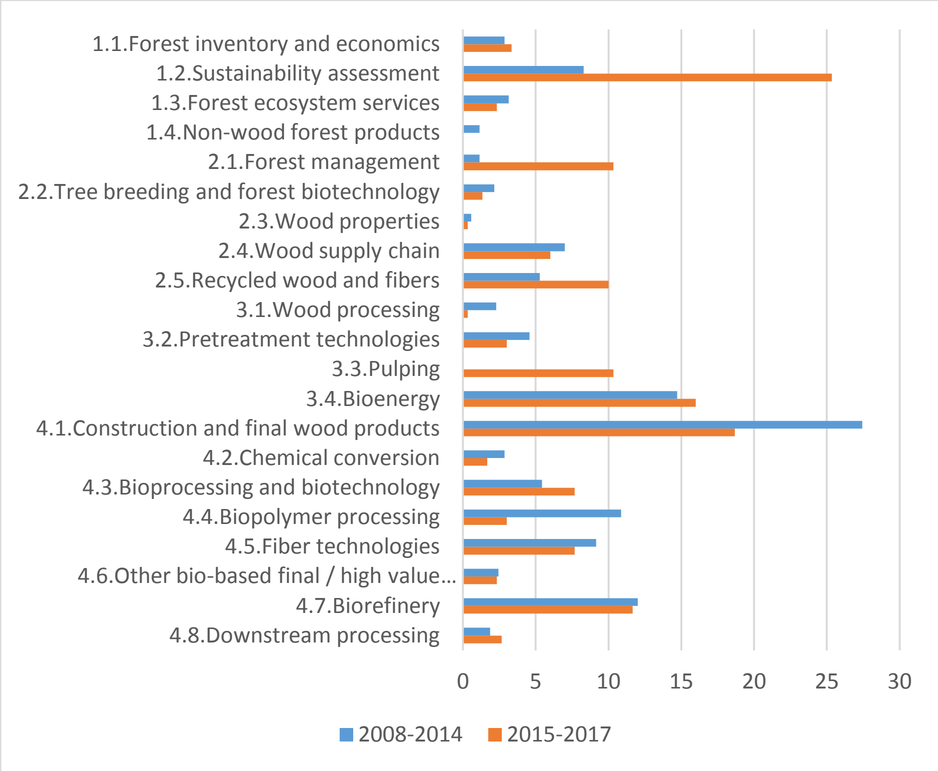

Figure 28. Annual average number of project participations per year per topic

The average number of project participations per year per topic has increased from the FP7 (5.9 participations; 2018-2014) to H2020 (6.8 participations; 2015-2017), where there are no projects in H2020 devoted to Non-Wood forest products (topic 1.4), and there were not projects in FP7 devoted to Pulping (topic 3.3). The greatest absolute increase in number of project participations per topic has occurred for 1.2 Sustainability assessment (from 8.3 in FP7 to 25.3 in H2020).

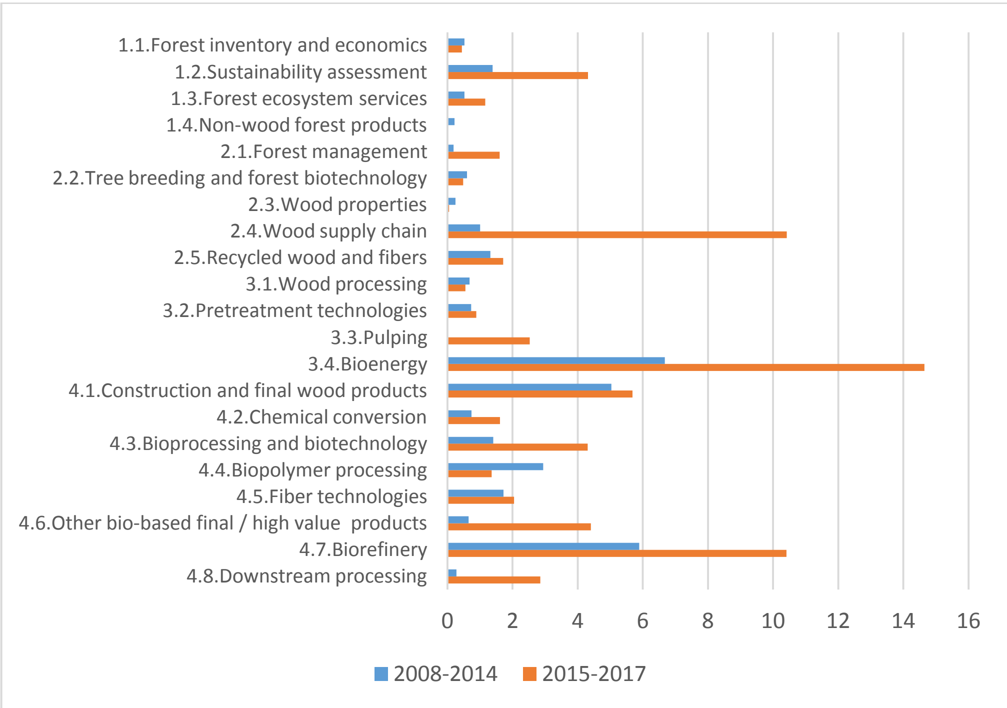

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Figure 29. Annual EC co-funding by topic

The triple number of annual project participations of topic 1.2 Sustainability assessment in H2020 compared to FP7 is equally matched in the change of annual EC's co-funding (Figure 29). However, topic 2.4.Wood supply chain and 4.8.Downstream processing have received tenfold increase in annual funding. In absolute terms, the highest level of change in annual funding is for the topics 2.4.Wood supply chain (9.4 mil. Euros) and 3.4.Bioenergy (8.0 mil. Euros), where they also receive largest annual funding within H2020 framework (14.7 and 10.42 mil. Euros, respectively). Topic 4.7.Biorefinery is also very close in terms of total EC's annual co-funding in H2020 (10.41 mil Euros).

4.5. Mapping innovations in forest bioeconomy

The first step in the analysis of the survey data was to compare it against the characteristics of the sampling frame, to see if the survey responses significantly differ from the population. Figure 30 shows distributions in the number of projects per topic, separately for the sampled responses and for the overall projects in the field of forest bioeconomy. In order to make them comparable, overall number of projects (387) has been cut by 62.6% to fit the sample size (i.e. the number sampled responses - 145).

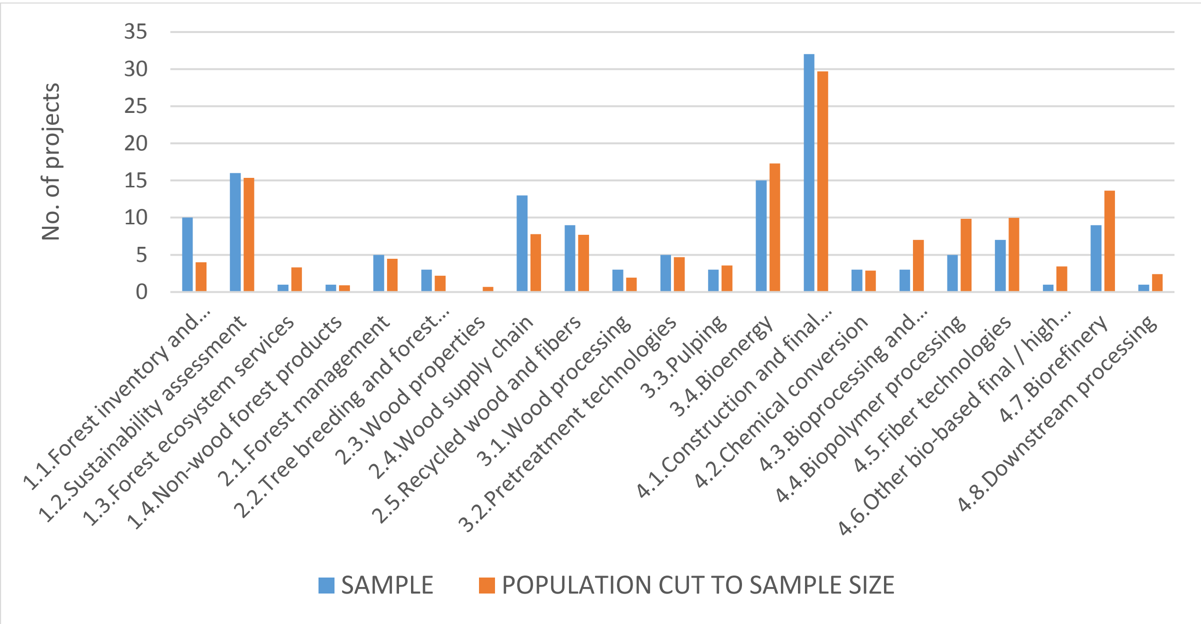

Figure 30. Comparison of sample and population

The number of projects by topic in the sampled responses closely follows the distribution of overall projects by topic and based on statistical testing (t-test for independent samples - p=0.867; 2-tailed; with 40 degrees of freedom and F=0.028) there are no significant differences.

Most of the respondents indicated to have been working on innovations related to production methods (30% of respondents), innovations related to goods (18%) and services (16%), while with the exception of Business practice / modes, all other types of innovation were selected by less than 10 percent of the respondents.

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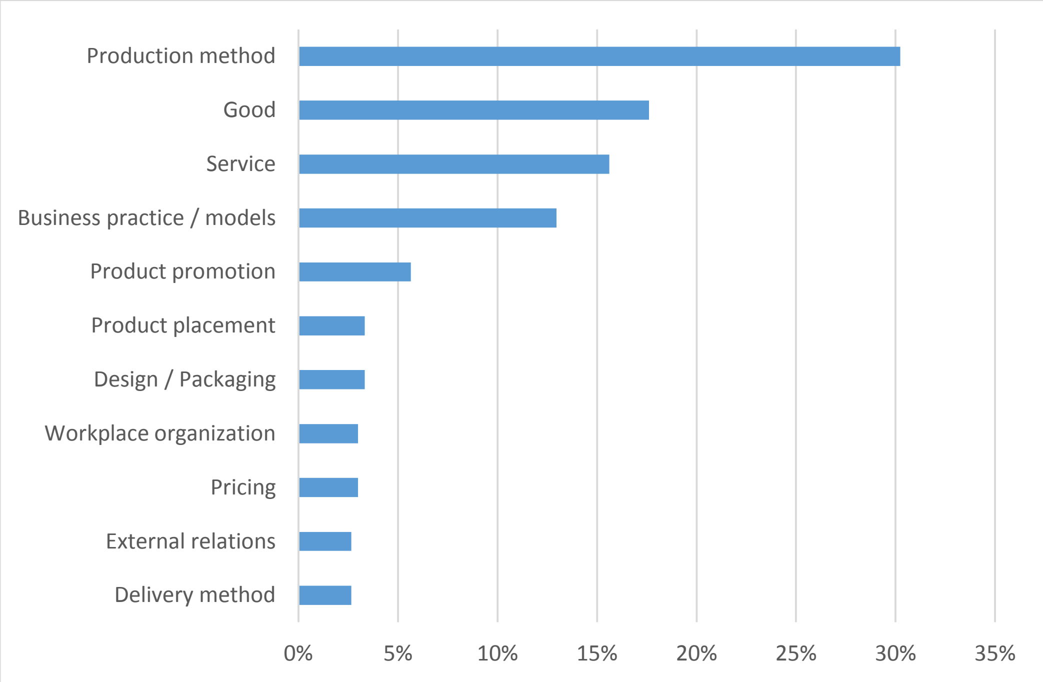

Figure 31. Types of innovation*

*Multiple responses were possible for this question

Figure 32 shows that following the innovation development, share of conducted work steadily grows from Idea generation (14%) to Design and development (25%), and strongly decreases in the subsequent stages of innovation development (marketing, initiation,…).

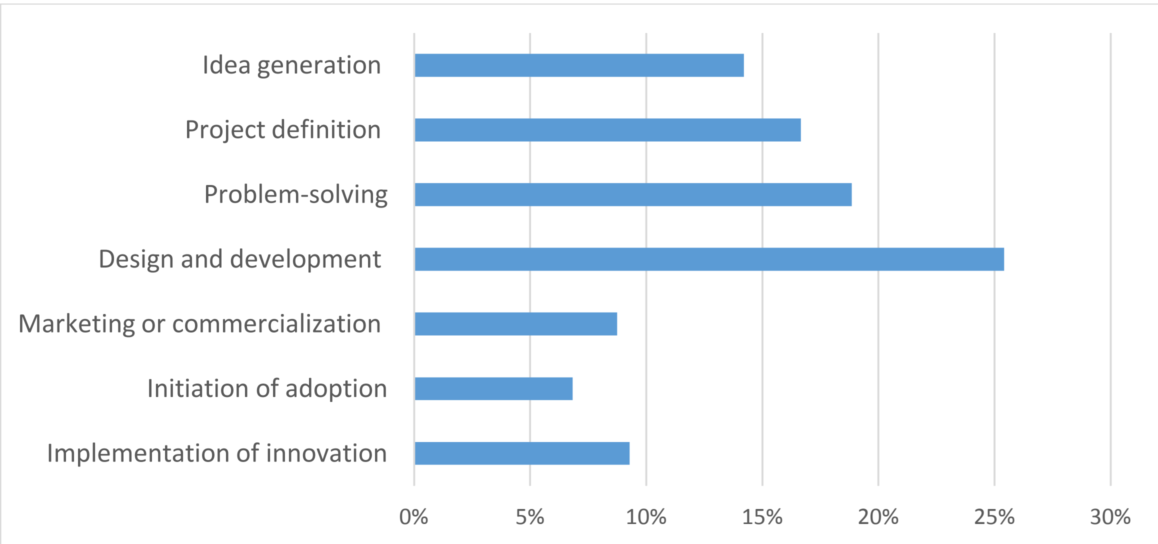

Figure 32. Stages of innovation development

Very similar responses were gathered on the Technology Readiness Levels of the innovation addressed in the projects (Figure 33).

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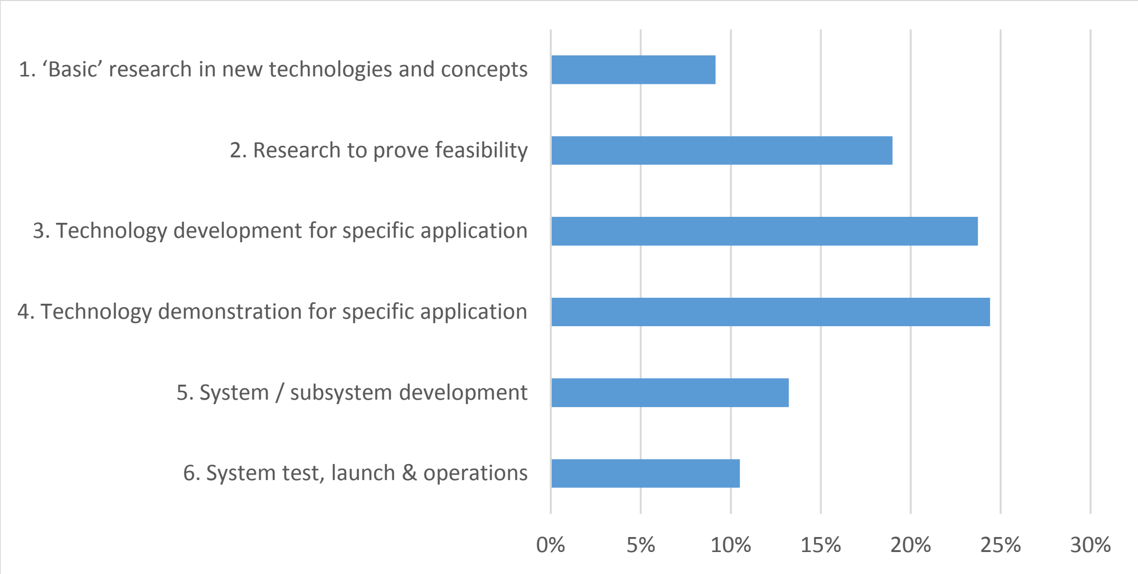

Figure 33. Technology Readiness Levels of the innovation

The share of innovations grows from 1. ‘Basic’ research in new technologies and concepts (9%) to 4. Technology demonstration for specific application (24%), only to sharply fall in the 5. System/subsystem development (13%) and 6. System test, launch & operations (11%).

The following set of questions focused on depicting different characteristics of innovations which were noted on a five-point Likert scale (Figure 34).

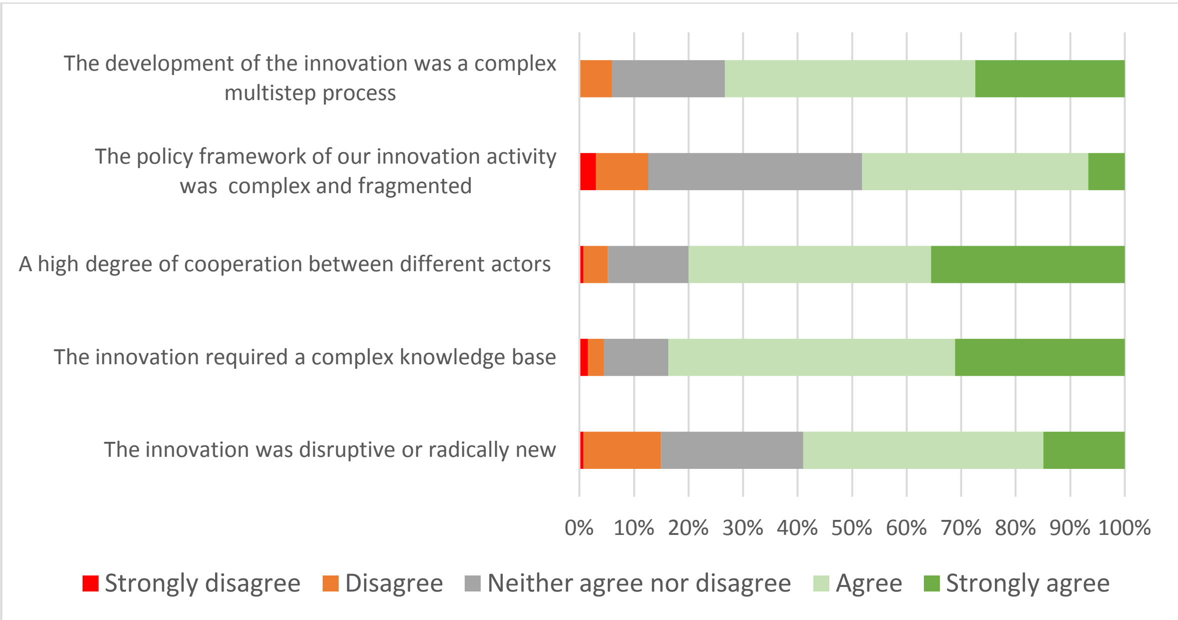

Figure 34. Descriptors of innovation

The large majority of respondents have stated that a high degree of cooperation between different actors was needed for the development of the respective innovations (80.0%), and that the innovation required a complex knowledge base (83.7%). The majority (73.3%) of respondents describes the development of innovation as a complex multistep process. About half respondents consider the innovation policy framework to be complex and fragmented (48.1%), and that the

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innovation was disruptive and radically new (59%). Much less variability in answers could be found in the case of internal organizational variables (Figure 35).

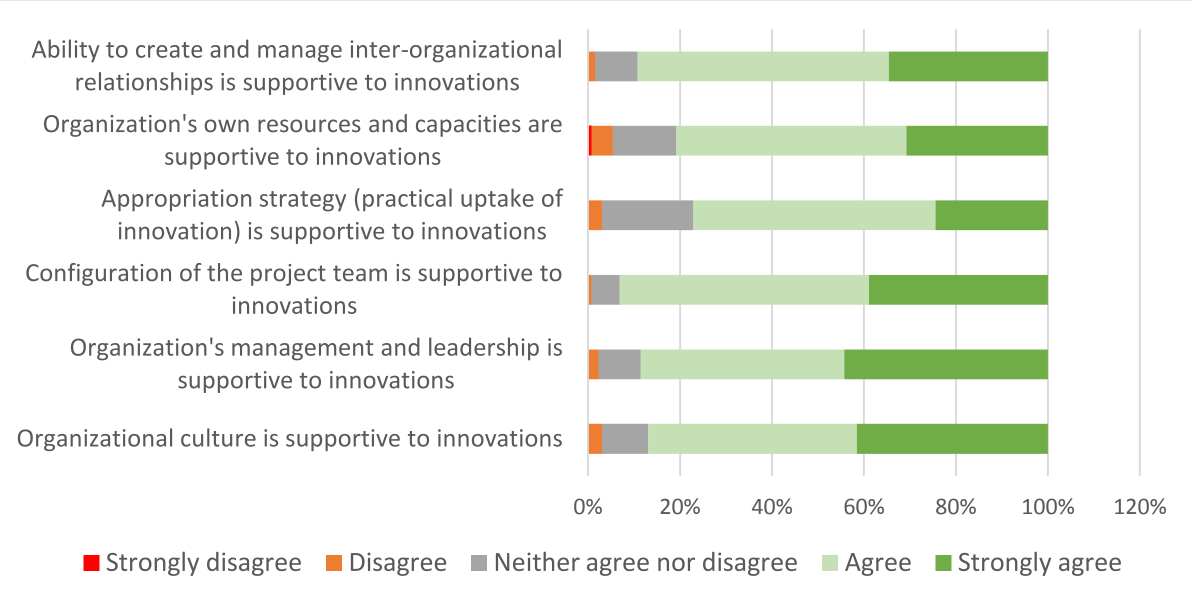

Figure 35. Internal organization variables of innovation

Respondents predominantly agree with all the statements that are related to internal organizational characteristics that may affect development of innovation. Configuration of the project teams is the most supportive variable of innovation (93.1%). The internal characteristic least supportive of innovation development is usage of own' organizational resources and capacities (5.4%). More diversity in responses can be found in Figure 36, which shows extent of collaboration with different external groups of actors in the process of innovation development.

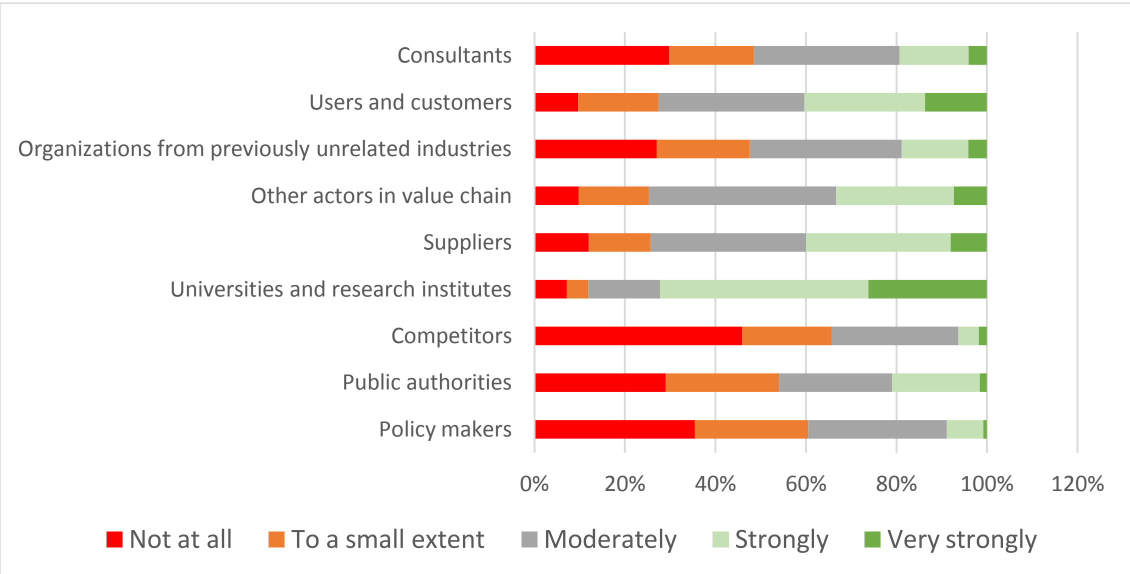

Figure 36. Collaboration and support from external groups of actors

Summing-up responses in the upper three response categories (from Moderately to Very strongly), it can be seen that sampled companies have most frequently collaborated with Universities and research institutes (88.1%). This result is affected by the selection of the overall sample, which is

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rooted in EC's research and innovation actions. Collaboration with all other actor groups is much less frequent. The least frequent (summing-up first two response categories) is the collaboration with policy makers (60.5%) and competitors (65.8%).

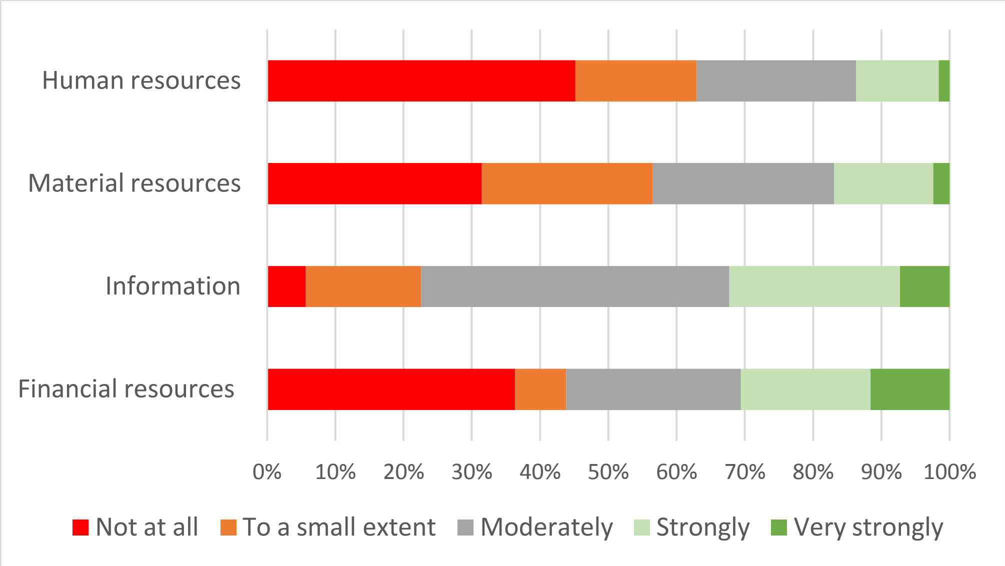
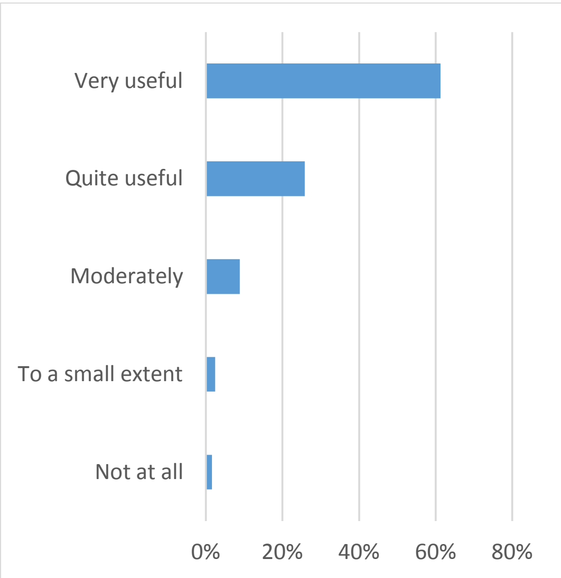


Figure 37. Resource-based innovation support

When respondents were asked what kind of resource-based support have they received from external organizations or individuals (Figure 37), they have most frequently received information (summing-up three upper response categories, 77.4%) followed by financial resources (56.2%), while only minority have received support in material (43.5%) and human (37.1%) resources.



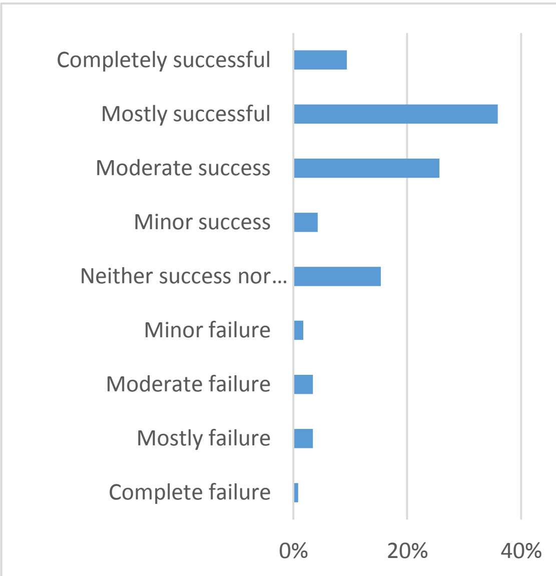


Figure 38. Usefulness of project for innovation development

Figure 39. Successfulness of innovation

The vast majority of respondents consider that EC's project are useful for innovation development (Figure 38), and that three quarters of all sampled innovations (Figure 39, summing-up all positive responses) were successful.

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Figure 40 shows that total innovation expenditure (not only EC project-related), expressed as percentage of total organizational revenue, is 17.4% (with median at 10.1%).

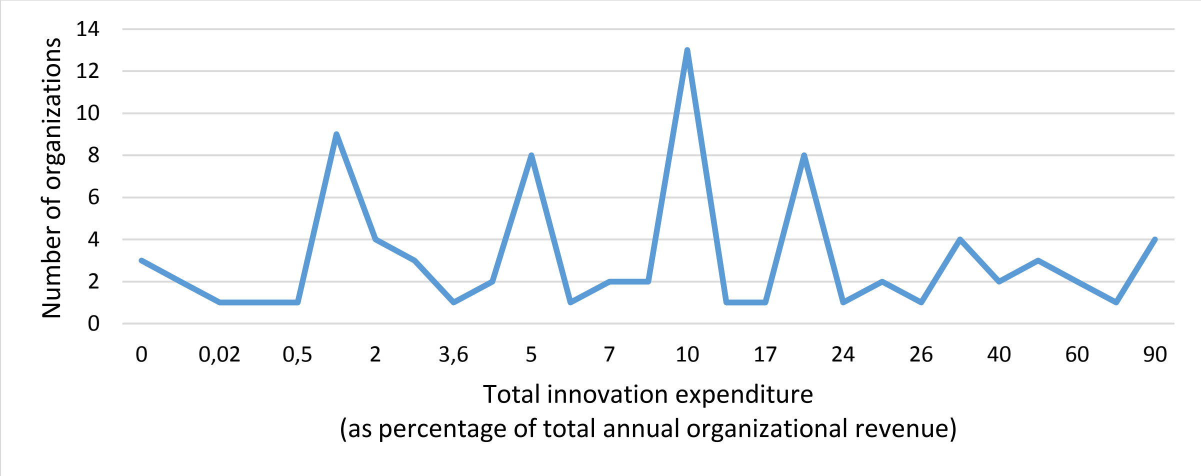

Figure 40. Total innovation expenditure by organization

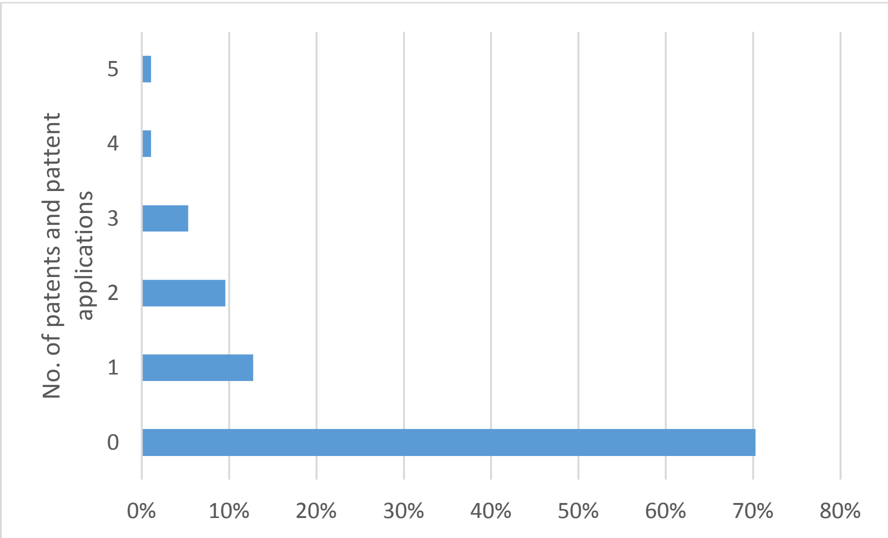

Figure 41. Number of patents and patent applications from the innovation cases

Seventy percent of innovation cases did not result with a patent application (Figure 41), while maximum number was five. Counting all valid responses (including those when no patents or patent applications), the average value of EC's funding per patent or patent application was 290 489 Euros. The average value of EC's funding per patent or patent application, counting only cases where at least one was created, was 104 386 Euros. Similar distribution with low values in majority of cases and high values in minority of cases is found in all subsequent outputs of innovation. The mean share of revenue from innovation cases was 9.3% but the median[1] was 1% and mean number of new products and services from innovation case was 2.28 but the median was 1. Same distribution is also

[1] Median is a better indicator of central tendency than the mean in cases when the distribution strongly deviates from the normal distribution (strong skewness and kurtosis).

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present for the main organizational descriptors; the mean number of employees was 430 while the median was 21, and mean annual revenue was 171 mil. Euros while the median was 2.5 mil. Euros. When total revenue stemming from innovation cases developed in sampled EC projects is compared to actual EC's funding for these project participations, this comparison results with multiplication factor of 2.84. This means that one Euro invested in EC research and innovation projects generates 2.84 Euros of revenue. However, twenty respondents that have reported on total organizational revenue have not reported how much revenue they have generated from innovation developed in sampled EC projects. If this 'missing' data on project innovation revenue is replaced my median value (1.75%) of innovation revenue, then multiplication factor is 6.23. The next step in the analysis was to compare (mostly and completely) successful innovation cases and the (mostly and completely) not successful innovation cases. This was done be grouping separately all successful and not successful innovations (i.e. first two and last two response categories as shown in Figure 39), and then comparing their values across all the independent variables (Table 2). The main findings of the comparison of these two groups of innovation cases are:

- The successful cases are equally distributed in the supply-chain classification of topics, while the not successful innovation cases are presented in the latter stages of the supply chain (primary and secondary processing).
- Successful innovations are also proportionally distributed across innovation types, while the not successful cases were mostly related to Product promotion.
- Both successful and not successful innovations are proportionally distributed among different innovation development stages.
- Successful innovations are much more radical, new and disruptive (e.g. redesigned business models or setup of completely new supply chains) than those which are not successful. Such characterization was attributed to 91% of successful innovations and to 40% of not successful innovations
- Successful innovation cases also required more complex knowledge base.
- Policy framework is also less complicated for not successful innovations, as 40% of them were characterized with simple policy framework, while this is less often the case with successful innovations (8%).
- Development of successful innovations is a complex and iterative process (for 83% of cases), while same can be stated only for 20% of not successful innovations.
- Almost all (96%) of successful innovations had support from organizational management, while this was less frequently (60%) the case for not successful innovations.
- Non-successful innovations are also characterized with lesser degree of cooperation with external actors than it is the case with successful ones.
- When it comes to a resource-based support, the most striking difference between successful and not successful innovation cases is in the provision of financial resources. Summing-up the share of responses in the bottom-two categories ('no support at all' and 'to a small extent'), 36% of successful innovations fall within these categories, while all not successful innovations fall within these categories (i.e. they have received little or no support).

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5. DISCUSSION AND CONCLUSIONS

5.1. Mapping of research capacities and activity

This report focuses on mapping and analysing research capacities and research activities in the field of forest bioeconomy in Europe. Although **each part of Europe has sizable capacities** in each segment of the supply chain, overall **capacities increase from Southern across Eastern and Northern to Western Europe**. On individual level, Northern European countries and organizations have the overall highest capacities in the field. From mapping of the **research capacities**, it is evident that they **increase along the supply chain**; and same can be stated for research funding. Although **overall funding of research increases** from FP7 to H2020, the increase is almost exclusively limited to intermediary steps of the supply chain. However, given the high share of EC's funding allocated to private companies in primary and secondary processing, research organizations get approximately evened-out funding along the supply chain. When looking at EC's funding in classical forestry topics, **biggest increase in funding occurred for Sustainability assessment**, and **biggest decrease was for Forest inventory and economics**. From all individual topics, **largest overall funding** and EC's funding was **devoted to Bioenergy**.

The definition of forest-bioeconomy is based on previous mapping exercises in the field and on opinions of five senior researchers. Although there was a high level of consensus, their opinions were not completely uniform, as not all researchers agreed to include or not forest ecosystem services, land use policy and forest ergonomics. Only topics listed in two ERIFORE's mapping exercises had detailed (textual) explanations, while in others only titles of topics or few key words were included. Only ERIFORE's bibliometric review had described the sampling procedure, while no other mapping exercise has done so. **Not all topics and countries were in the scope of all the mapping exercises**; which means that results focused on more frequently listed topics and countries have more validity than the ones describing capacities in topics and countries that were listed only in a couple of mapping exercises. The procedure of extracting topic-by-organization capacities from FORESTERRA has produced a positive discrimination towards capacities of larger organizations. **Assessing regional-level results has to be done with a reference to which countries fall in what region**; e.g. Baltic states are listed within Eastern Europe, and France is listed within Western Europe, although it is also encompassed in FORESTERRA's assessment of Mediterranean research capacities.

Research activity has been proxied by funding received in FP7, H2020 and several ERA-NETs. Authors acknowledge that such **data frame does not reflect overall research activity in Europe**, where there might be many national and other international research funding sources. Received funding also produces divergent research activity throughout Europe; e.g. a certain amount of funding that can support a researcher in Finland for one month can support a same level researcher in Croatia for three months. Two researchers have independently performed the project sampling and the topic-categorization procedure, and then cross-validated their results. The overlap in defining the overall sample was 97%, while the overlap in assigning topics to individual projects was 91%. Defining the overall sample was not problematic, but **assigning topics-by-projects was problematic.** Many projects contain elements from different topics, and the descriptions of projects were sometimes inadequate to make the judgement (about 30% of projects was also checked by reading their web-sites). the following examples demonstrate the problems faced in sampling and categorization

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procedure. BIOFOAMBARK project (Bark Valorization into Insulating Foams and Bioenergy, classified in 4.4.Biopolymer processing) tackles topics of bioenergy, sustainability assessment and supply-chain analysis; but the primary focus is on use of polymers as foam-building material as substitution to petroleum-based plastics, followed by end-of life conversion into syngas. Another example is ReWoBioRef project (Mobilization and utilization of recycled wood for lignocellulosic bio-refinery processes, classified in 2.5.Recycled wood and fibres) that is also strongly linked to biorefinery topic (3.7). Previously mentioned project GEM-TRAIT focuses on tropical forests; but as the research is conducted by University of Oxford and University of Leeds, it is encompassed in the sample. Similar dilemma was with 2G BIOPIC project that focuses on production of bioethanol from agricultural residues and wood; which was encompassed in the sample although it is equally rooted in agriculture and forestry.

The large data sets obtained in this study allow for many cross-tabulation options, and some of them have been presented in the results section. The selection of results was intended to provide an overall description of research activities and capacities within forest-bioeconomy in Europe, and does not go into details of individual countries and topics, nor does it contain explanatory inferential analysis. The most striking misbalance in project funding is the **low level of received EC's funding compared to high capacities in Eastern Europe.** This indicates that they are not adequately integrated into international scientific community of the field. Leading organizations from Northern and Western Europe should assist them in this issue. These category-specific linkages across organizations from different regions of Europe can be found in the section devoted to collaboration analysis. From a strategic research-planning perspective, the most important finding of the study is that the concept of **forest bioeconomy is not really a field of its own** (as operationalized in the supply-chain categorization of topics). Almost completely different organizations are active in different segments of the chain, transitioning from more forestry-oriented organizations such as EFI and BOKU at the beginning to more technology oriented ones at the end, such as VTT and FCBA. This discontinuity in the collaboration across topics is expected, given the fact that the complexity of supply chain greatly increases along each of its steps, and very different expertise are needed to tackle issues focused at its beginning and its end. The **low level of collaboration between actors in different categories** of topics inhibits innovative research-driven responses to policy challenges that require mobilization of entire forestry chains and systems (from raw materials to final products end of life). The analysis performed in this report points to **two policy recommendations** for the level of EU research and innovation planning:

- Support higher involvement of research organizations from Eastern European countries to the international scientific community within the field of forest bioeconomy by emphasizing criterion of geographical coverage in future research and innovation planning.
- Design research and innovation calls for projects that thematically cover multiple forest bioeconomy supply-chain categories.

5.2. Mapping of innovations

When it comes to organizational-level innovation development in the field of forest bioeconomy, several policy-relevant conclusions can be drawn from this study. **There are only few innovation cases in later stages of development**, which points to a need to modify the EC's research and

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innovation calls for project proposals in order to remedy this shortcoming. On a more positive note, **EU projects are considered as a useful framework for development of innovations**, and **most of innovation cases are judged as successful**. Most pronounced collaboration of private companies in the innovation development is with universities and research institutes. However, this is impacted by the sample selection. The sample selection is also the biggest limitation to the validity of the study, as it operates with an assumption that the sample is an adequate proxy to the overall innovation developments in the field of forest bioeconomy. This assumption cannot be tested, and thus interpretation of results should be taken-up with bearing in mind the limitations of the sample. The results also showed that the innovation cases of the responses are similar to the innovation cases of the overall sample, and that they are most frequent and most abundantly financed in the latter stages of the supply chain, i.e. in the topic encompassed by primary and secondary processing. **There are also few topics within which most of the innovations are situated: Sustainability assessment, Forest management, Wood supply chains, Bioenergy and Biorefineries**. The discrimination between successful and unsuccessful innovation cases has pointed-out to several measures through which support to innovation can be provided from the strategic position of EU and its member countries: (1) **more disruptive and complex innovations encompassing different policy spheres should be endorsed on the account of more 'routine' and 'safe' innovations**; (2) **successful innovations require strong support from variety of external actors**; (3) **successful innovations do not occur without adequate support from organizational leadership**; and (4) **successful innovations require substantial financial support** and not just information-based resources that are most frequently provided to the private companies within the framework of sampled projects.

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6. REFERENCES

1. Aguilar, A., Magnien, E. and Thomas, D., 2013. Thirty years of European biotechnology programmes: from biomolecular engineering to the bioeconomy. *New biotechnology*, *30*(5), pp.410-425.
2. Almirall, E., Lee, M. and Majchrzak, A., 2014. Open innovation requires integrated competition-community ecosystems: Lessons learned from civic open innovation. *Business Horizons*, *57*(3), pp.391-400.
3. Arnold, M. and Barth, V., 2012. Open innovation in urban energy systems. *Energy efficiency*, *5*(3), pp.351-364.
4. Belderbos, R., Cassiman, B., Faems, D., Leten, B. and Van Looy, B., 2014. Co-ownership of intellectual property: Exploring the value-appropriation and value-creation implications of co-patenting with different partners. *Research Policy*, *43*(5), pp.841-852.
5. Berkhout, G., Hartmann, D. and Trott, P., 2010. Connecting technological capabilities with market needs using a cyclic innovation model. *R&d Management*, *40*(5), pp.474-490.
6. Bigliardi, B. and Galati, F., 2013. Models of adoption of open innovation within the food industry. *Trends in Food Science & Technology*, *30*(1), pp.16-26.
7. Bigliardi, B., Ivo Dormio, A. and Galati, F., 2012. The adoption of open innovation within the telecommunication industry. *European Journal of Innovation Management*, *15*(1), pp.27-54.
8. Boehlje, M. and Bröring, S., 2011. The increasing multifunctionality of agricultural raw materials: Three dilemmas for innovation and adoption. *International Food and Agribusiness Management Review*, *14*(2), pp.1-16.
9. Boons, F., Montalvo, C., Quist, J. and Wagner, M., 2013. Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production*, *45*, pp.1-8.
10. Boons, F., Montalvo, C., Quist, J. and Wagner, M., 2013. Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production*, *45*, pp.1-8.
11. Brettel, M. and Cleven, N.J., 2011. Innovation culture, collaboration with external partners and NPD performance. *Creativity and Innovation Management*, *20*(4), pp.253-272.
12. Chesbrough, H. and Schwartz, K., 2007. Innovating business models with co-development partnerships. *Research-Technology Management*, *50*(1), pp.55-59.
13. Chesbrough, H., 2012. Open innovation: Where we've been and where we're going. *Research-Technology Management*, *55*(4), pp.20-27.
14. Chesbrough, H.W., 2006. *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press.
15. Cohen, W.M. and Levinthal, D.A., 1990. Absorptive capacity: A new perspective on learning and innovation. *Administrative science quarterly*, pp.128-152.
16. Cooke, P., Uranga, M.G. and Etxebarria, G., 1997. Regional innovation systems: Institutional and organisational dimensions. *Research policy*, *26*(4-5), pp.475-491.
17. Cooper, R.G. and Kleinschmidt, E.J., 1995. Benchmarking the firm's critical success factors in new product development. *Journal of product innovation management*, *12*(5), pp.374-391.

EUROPEAN UNION
Project co-funded by
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Grant Agreement n° 727486

18. Du, J., Leten, B. and Vanhaverbeke, W., 2014. Managing open innovation projects with science-based and market-based partners. *Research Policy*, *43*(5), pp.828-840.
19. Edison, H., Bin Ali, N. and Torkar, R., 2013. Towards innovation measurement in the software industry. *Journal of Systems and Software*, *86*(5), pp.1390-1407.
20. Enkel, E., Bell, J. and Hogenkamp, H., 2011. Open innovation maturity framework. *International Journal of Innovation Management*, *15*(06), pp.1161-1189.
21. European Bioeconomy Panel, Case studies of market-making in the bioeconomy, 2014. http://ec.europa.eu/research/bioeconomy/index.cfm?pg¼policy&lib¼panel
22. European Commission, Communication from the Commision to the European Parliament, the Council, the European Economic and Social Committee and the Commitee of the Regions-Innovating for Sustainable Growth: a Bioeconomy for Europe, European Commission, Brussels, Belgium, 2012.
23. Federal Ministry of Education and Research, National Research Strategy BioEconomy 2030 Our Route towards a Biobased Economy, 2011. www.bmbf.de/pub/bioeconomy_2030.pdf.
24. Fetterhoff, T.J. and Voelkel, D., 2006. Managing open innovation in biotechnology. *Research-Technology Management*, *49*(3), pp.14-18.
25. Frambach, R.T., Barkema, H.G., Nooteboom, B. and Wedel, M., 1998. Adoption of a service innovation in the business market: an empirical test of supply-side variables. *Journal of Business Research*, *41*(2), pp.161-174.
26. Gallagher, K.S., Grübler, A., Kuhl, L., Nemet, G. and Wilson, C., 2012. The energy technology innovation system. *Annual Review of Environment and Resources*, *37*, pp.137-162.
27. Giannopoulou, E., Yström, A. and Ollila, S., 2011. Turning open innovation into practice: Open innovation research through the lens of managers. *International Journal of Innovation Management*, *15*(03), pp.505-524.
28. Golembiewski, B., Sick, N. and Bröring, S., 2015. The emerging research landscape on bioeconomy: What has been done so far and what is essential from a technology and innovation management perspective?. *Innovative Food Science & Emerging Technologies*, *29*, pp.308-317.
29. Gopalakrishnan, S. and Damanpour, F., 1997. A review of innovation research in economics, sociology and technology management. Omega, 25(1), pp.15-28.
30. Grote, M., Herstatt, C. and Gemünden, H.G., 2012. Cross-Divisional Innovation in the Large Corporation: Thoughts and Evidence on Its Value and the Role of the Early Stages of Innovation. *Creativity and Innovation Management*, *21*(4), pp.361-375.
31. Hadorn, G.H., Bradley, D., Pohl, C., Rist, S. and Wiesmann, U., 2006. Implications of transdisciplinarity for sustainability research. *Ecological economics*, *60*(1), pp.119-128.
32. Hansen, M.T. and Birkinshaw, J., 2007. The innovation value chain. *Harvard business review*, *85*(6), p.121.
33. Hermans, F., Stuiver, M., Beers, P.J. and Kok, K., 2013. The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. *Agricultural Systems*, *115*, pp.117-128.
34. Herskovits, R., Grijalbo, M. and Tafur, J., 2013. Understanding the main drivers of value creation in an open innovation program. *International Entrepreneurship and Management Journal*, *9*(4), pp.631-640.
35. Holl, A. and Rama, R., 2012. Technology sourcing: Are biotechnology firms different? An exploratory study of the Spanish case. *Science and Public Policy*, *39*(3), pp.304-317.
36. Huang, F., Rice, J., Galvin, P. and Martin, N., 2014. Openness and appropriation: empirical evidence from Australian businesses. *IEEE Transactions on Engineering Management*, *61*(3), pp.488-498.

EUROPEAN UNION
Project co-funded by
H2020 Programme under
Grant Agreement n° 727486

37. Huston, L. and Sakkab, N., 2004. Connect and develop: inside Procter & Gamble's new model for innovation, Harv. Bus. Rev. 84 (2004) 58-66
38. Johnson, T.G. and Altman, I., 2014. Rural development opportunities in the bioeconomy. *biomass and bioenergy*, *63*, pp.341-344.
39. Kircher, M., 2012. The transition to a bio-economy: national perspectives. *Biofuels, Bioproducts and Biorefining*, *6*(3), pp.240-245
40. Kircher, M., 2012. The transition to a bio-economy: national perspectives. *Biofuels, Bioproducts and Biorefining*, *6*(3), pp.240-245.
41. Kleinknecht, A., Van Montfort, K. and Brouwer, E., 2002. The non-trivial choice between innovation indicators. *Economics of Innovation and new technology*, *11*(2), pp.109-121.
42. Kleinschmit, D., Lindstad, B.H., Thorsen, B.J., Toppinen, A., Roos, A. and Baardsen, S., 2014. Shades of green: a social scientific view on bioeconomy in the forest sector. *Scandinavian journal of forest research*, *29*(4), pp.402-410.
43. Kutvonen, A., 2011. Strategic application of outbound open innovation. *European Journal of Innovation Management*, *14*(4), pp.460-474.
44. L. Staffas, M. Gustavsson, K. McCormick, Strategies and policies for the bioeconomy and bio-based economy: an analysis of official national approaches, Sustain 5 (2013) 2751-2769
45. Laursen, K. and Salter, A.J., 2014. The paradox of openness: Appropriability, external search and collaboration. *Research Policy*, *43*(5), pp.867-878.
46. Lichtenthaler, U., 2013. The collaboration of innovation intermediaries and manufacturing firms in the markets for technology. *Journal of Product Innovation Management*, *30*(S1), pp.142-158.
47. Malerba, F., 2002. Sectoral systems of innovation and production. *Research policy*, *31*(2), pp.247-264.
48. Mankins, J.C., 1995. Technology readiness levels. White Paper, April, 6.
49. McCormick, K. and Kautto, N., 2013. The bioeconomy in Europe: An overview. *Sustainability*, *5*(6), pp.2589-2608.
50. Melese, T., Lin, S.M., Chang, J.L. and Cohen, N.H., 2009. Open innovation networks between academia and industry: an imperative for breakthrough therapies. *Nature medicine*, *15*(5), pp.502-507.
51. Miller, D.J., Fern, M.J. and Cardinal, L.B., 2007. The use of knowledge for technological innovation within diversified firms. *Academy of Management Journal*, *50*(2), pp.307-325.
52. Mina, A., Bascavusoglu-Moreau, E. and Hughes, A., 2014. Open service innovation and the firm's search for external knowledge. *Research Policy*, *43*(5), pp.853-866.
53. Nakagaki, P., Aber, J. and Fetterhoff, T., 2012. The challenges in implementing open innovation in a global innovation-driven corporation. *Research-Technology Management*, *55*(4), pp.32-38.
54. OECD (2005): Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data. Paris, OECD
55. OECD, 2009 The Bioeconomy to 2030-Designing a Policy Agenda, Paris, France, 2009.
56. Ollikainen, M., 2014. Forestry in bioeconomy–smart green growth for the humankind. Scandinavian journal of forest research, 29(4), pp.360-366.
57. Ollila, S. and Elmquist, M., 2011. Managing open innovation: Exploring challenges at the interfaces of an open innovation arena. *Creativity and Innovation Management*, *20*(4), pp.273-283.
58. Pfau, S.F., Hagens, J.E., Dankbaar, B. and Smits, A.J., 2014. Visions of sustainability in bioeconomy research. *Sustainability*, *6*(3), pp.1222-1249.
59. Philp, J.C., Ritchie, R.J. and Guy, K., 2013. Biobased plastics in a bioeconomy. *Trends in biotechnology*, *31*(2), pp.65-67.

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60. Pohl, C., 2005. Transdisciplinary collaboration in environmental research. *Futures*, *37*(10), pp.1159-1178.
61. Pohl, C., 2008. From science to policy through transdisciplinary research. *environmental science & policy*, *11*(1), pp.46-53.
62. Pride, W.M., Hughes, R.J. and Kapoor, J.R., 1991. Business. Boston, US.
63. Pülzl, H., Kleinschmit, D. and Arts, B., 2014. Bioeconomy–an emerging meta-discourse affecting forest discourses?. *Scandinavian Journal of Forest Research*, *29*(4), pp.386-393.
64. Ritter, T. and Gemünden, H.G., 2004. The impact of a company's business strategy on its technological competence, network competence and innovation success. *Journal of business research*, *57*(5), pp.548-556.
65. Salter, A., Criscuolo, P. and TerWal, A.L., 2014. Coping with open innovation. *California Management Review*, *56*(2), pp.77-94.
66. Sandmeier, P., Jamali, N., Kobe, C., Enkel, E., Gassmann, O. and Meier, M., 2004. Towards a structured and integrative front-end of product innovation.
67. Scar, E.U., 2012. Agricultural knowledge and innovation systems in transition–a reflection paper. *European Commisssion, Standing Commitee on Agricultural Research-Collaborative Working Group on Agricultural Knowledge and Innovation System (CWG AKIS), Brussels*.
68. Schaltegger, S., Beckmann, M. and Hansen, E.G., 2013. Transdisciplinarity in corporate sustainability: mapping the field. *Business Strategy and the Environment*, *22*(4), pp.219-229.
69. Schmidt, O., Padel, S. and Levidow, L., 2012. The bioeconomy concept and knowledge base in a public goods and farmer perspective. *Bio-based and Applied Economics*, *1*(1), pp.47-63.
70. Sisodiya, S.R., Johnson, J.L. and Grégoire, Y., 2013. Inbound open innovation for enhanced performance: Enablers and opportunities. *Industrial Marketing Management*, *42*(5), pp.836-849.
71. Staffas, L., Gustavsson, M. and McCormick, K., 2013. Strategies and policies for the bioeconomy and bio-based economy: An analysis of official national approaches. *Sustainability*, *5*(6), pp.2751-2769.
72. Van Lancker, J., Wauters, E. and Van Huylenbroeck, G., 2016. Managing innovation in the bioeconomy: An open innovation perspective. Biomass and Bioenergy, 90, pp.60-69.
73. Vandermeulen, V., Van der Steen, M., Stevens, C.V. and Van Huylenbroeck, G., 2012. Industry expectations regarding the transition toward a biobased economy. *Biofuels, Bioproducts and Biorefining*, *6*(4), pp.453-464.
74. Veldkamp, A., Van Altvorst, A.C., Eweg, R., Jacobsen, E., Van Kleef, A., Van Latesteijn, H., Mager, S., Mommaas, H., Smeets, P.J.A.M., Spaans, L. and Van Trijp, J.C.M., 2009. Triggering Transitions Towards Sustainable Development of the Dutch Agricultural Sector: Trans Forum's Approach. In *Sustainable agriculture* (pp. 673-685). Springer Netherlands.
75. West, J. and Bogers, M., 2014. Leveraging external sources of innovation: a review of research on open innovation. *Journal of Product Innovation Management*, *31*(4), pp.814-831.
76. Westergren, U.H. and Holmström, J., 2012. Exploring preconditions for open innovation: Value networks in industrial firms. *Information and Organization*, *22*(4), pp.209-226.

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Appendix I. Detailed classification of topics

Table 1. Key words and project examples of individual topics

CATEGORY	TOPIC	KEY WORDS / AREAS	Project example
FOREST SYSTEMS	1.1.Forest inventory and economics	Forest survey, mapping, remote sensing, wood availability, forest economics, yield..	STRUCCHANGE (Monitoring forest degradation using terrestrial lidar and satellite images)
	1.2.Sustainability assessment	Sustainability impact assessment, LCA, socio-economic-environmental trade-offs,	ECOTOOL (Improving Life Cycle analysis tools for sustainability assessment in forestry, agriculture and environment technologies)
	1.3.Forest ecosystem services	Biodiversity, recreation, carbon sequestration, PES….	NEWFOREX (New Ways to Value and Market Forest Externalities)
	1.4.Non-wood forest products	Berries, mushrooms, medicinal herbs…	STAR TREE (Multipurpose trees and non-wood forest products a challenge and opportunity)
FOREST BIOMASS & RAW MATERIALS	2.1.Forest management	Silviculture, harvesting, forest operations, plantation forestry	EURSDM (Elaboration of advanced-level models for density management of coniferous and broadleaved even-aged natural stands and plantations in Europe)
	2.2.Tree breeding and forest biotechnology	Tree breeding, forest genetics, tree improvement, DNA	PROCOGEN (Promoting a functional and comparative understanding of the conifer genome- implementing applied aspects for more productive and adapted forests)
	2.3.Wood properties	Wood quality, physical, chemical and mechanical properties	WOVEN (Wood formation under varying environmental conditions)
	2.4.Wood supply chain	Wood fuel and biomass supply, forest logistics, ICT,	BioRES (Sustainable Regional Supply Chains for Woody Bioenergy)
	2.5.Recycled wood and fibres	Waste, recycled wood, pulp	WPF (From Waste Paper to Furniture)

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CATEGORY	TOPIC	KEY WORDS / AREAS	Project example
PRIMARY PROCESSING	3.1.Wood processing	Sawmilling, Wood modification, Processing techniques, technological aspects of wood	VARMA (Value added by optimal wood raw material allocation and processing)
	3.2.Pretreatment technologies	Physico-mechanical, chemical and biological treatment; steam CO2 and ammonia fibre explosion…	TORCHWOOD (Development of an affordable heat treatment process for wood)
	3.3.Pulping	cooking the raw lignocellulos material and pulp purification	PROVIDES (PROcesses for Value added fibres by Innovative Deep Eutectic Solvents)
	3.4.Bioenergy	Thermochemical conversions (torrefaction, pyrolysis, gasification), pelletizing, production and usage of biofuels	BIOCHIPFEEDING (Wood chip feeding technology of the future for small-scale biomass boilers)
SECONDARY PROCESSING	4.1.Construction and final wood products	Usage of wood in construction, furniture, Conversion, shaping, assembly and finishing of wood products…	BEST (Building with Environmentally Sustainable Structural Timber)
	4.2.Chemical conversion	Manufacturing, testing, screening and evaluation of new catalysts	BIOXCAT (Bioinspired Catalysts for Commercial Applications)
	4.3.Bioprocessing and biotechnology	enzymatic and whole cell catalysis for conversion of lignocellulose	FALCON (Fuel and chemicals from lignin through enzymatic and chemical conversion)
	4.4.Biopolymer processing	compounding, extrusion, injection moulding, thermomolding or infusion of thermoplastic and thermosetting biopolymers	MouldPulp (Development of Durable, Fully Bio-Based Thermoplastic Composites from Bioplastics and Pulp Fibres for Injection Moulding Applications)

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	4.5.Fiber technologies	extraction and the synthesis of lignocellulosicfibers and their transformation into fiber based webs or textiles	ADCELLPACK (Advanced cellulose packaging)
	4.6.Other bio-based final / high value products	biopharmaceuticals, cellulose-based carbon-fibres and aerogels..	ReCell (Refined cellulose derivatives for high-value biomedical products)
	4.7.Biorefinery	Practical and theoretical biorefinery development	EUROBIOREF (EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing)

Table 2. Key words and research areas of each mapping exercise per topic.

1. FOREST SYSTEMS	**ERIFORE – survey**	**ERIFORE – Bibliometric**	**INOWAWOOD**	**WoodWisdom**	**SUMFOREST**	**FORESTERRA**
1.1. forest inventory and economics	Forest inventory and wood availability	Forest inventory and wood availability	Marketing and economics		Forest mensuration (topic 5) + Marketing and Economics (topi 7) + T9- Forest labour questions	Forest Inventory; Forest Planning & Inventory; Remote sensing; ; Yield and Economics
1.2. Sustainability assessment	Sustainability assessment tools (environmental, social, economics)	Sustainability assessment tools (environmental, social, economics)		Sustainability	T9 - Forest taxation + Afforestation policy T9 - Land use, land-use policy.	Social Forestry
1.3.forest ecosystem services			ecological and social services			
1.4.Non-wood forest products					Minor forest products	Non-wood forest products
2. FOREST BIOMASS & RAW MATERIALS						
2.1. Forest management	Silviculture	Silviculture	Silviculture + Harvesting + Forest management	Sliviculture + procurement and harvesting	Sliviculture and its subtopics (topics 2) + harvesting and logging (topic 3) + forest management (topic 6) + Work science / forest ergonomics (in topic 3)	Forest Operations; Silviculture; Wood Harvesting;

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2.2.Tree breeding and forest biotechnology	Tree breeding and forest biotechnology	Tree breeding and forest biotechnology		Wood formation and breeding		Forest Genetics; Forest Genetics & Forest Biotechnology; Seed and Tree Breeding;
2.3. Wood properties	Wood quality assessment and suitability between biomass and processing	Wood quality assessment and suitability between biomass and processing	Physical properties of wood + Mechanical properties + Chemical properties of wood + Quality grading of wood	Raw material properties of wood + material properties of wood and fibres	T8. - Wood and bark: structure and properties T8 - Grading of wood and wood products T8. - Preservative and other treatments to improve the properties of wood. Damage by biological agencies and its control	Wood Technology
2.4. Wood supply chain	Wood supply chain, logistics, transportation	Wood supply chain, logistics, transportation		Forestry wood chain	Timberyard practice (handling and storage)	
2.5.Recycled wood and fibers	Recycled wood and fibers	Recycled wood and fibers				
3. PRIMARY PROCESSING						
3.1.Wood processing			Wood modification + Processing techniques and technological aspects of wood	Processing and manufacturing		
3.2.Pretreatment technologies	Pretreatment technologies					
3.3.Pulping	Pulping				T8. Pulp industries Composite materials made wholly or partly from woody matter. Chemical utilization of wood	
3.4.Bioenergy	Thermochemical conversion			Bioenergy / pelletizing		Biomass for bioenergy production
4. SECONDARY PROCESSING						
4.1. Construction and final wood products			Production aspects of wood	Construction and building + wood products	T8. - Conversion, shaping, assembly and finishing of wood: general T8. - Timber manufacturing industries and products. Uses of wood as such	Wood products

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					T8 - Economy in the use of wood. Replacement by competitive materials	
4.2.Chemical conversion	Chemical conversion					
4.3.Bioprocessing and biotechnology	Bioprocessing and biotechnology					Biotechnology
4.4.Biopolymer processing	Biopolymer processing					
4.5.Fiber technologies	Fiber technologies			fibre products		
4.6.Other bio-based final / high value products	Other bio-based final / high value products			other wood-based products		
4.7.Biorefinery	Alsobiorefinery mentioned here! –in Deliverables!			Biorefinery		
4.8. Downstream processing	Downstream processing					

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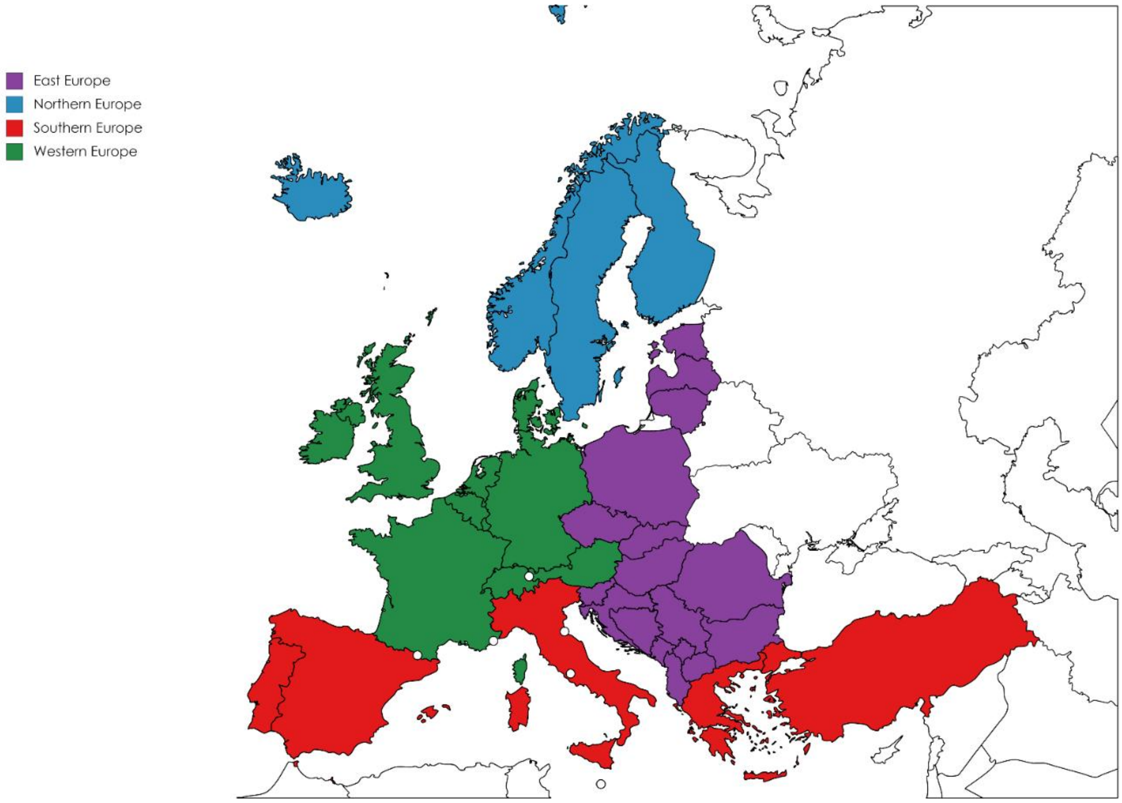

Figure 1. Regions of Europe

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Appendix II. Additional results from the mapping of capacities in forest bioeconomy

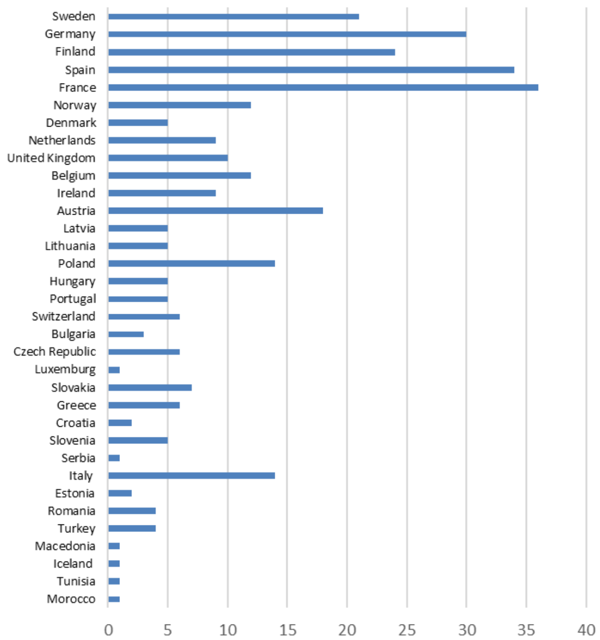

Figure 1. Count of organizations by country

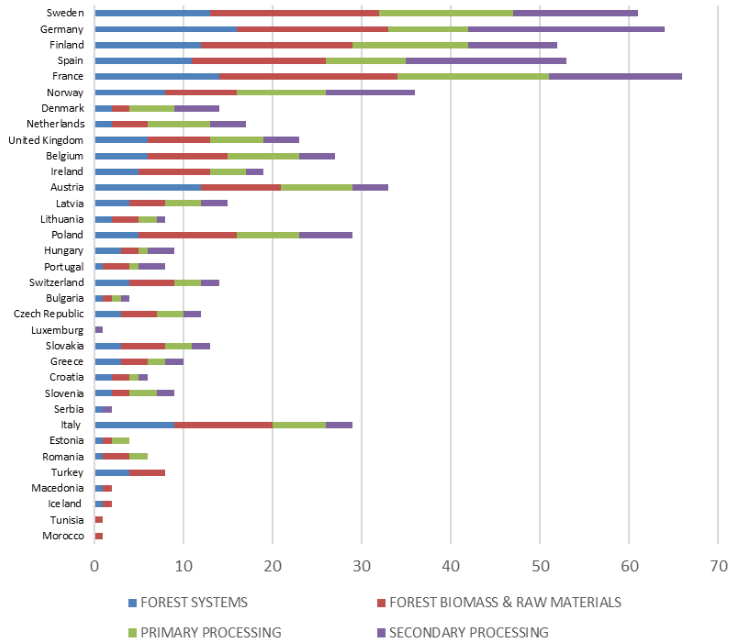

Figure 2. Count of organizational capacities by country

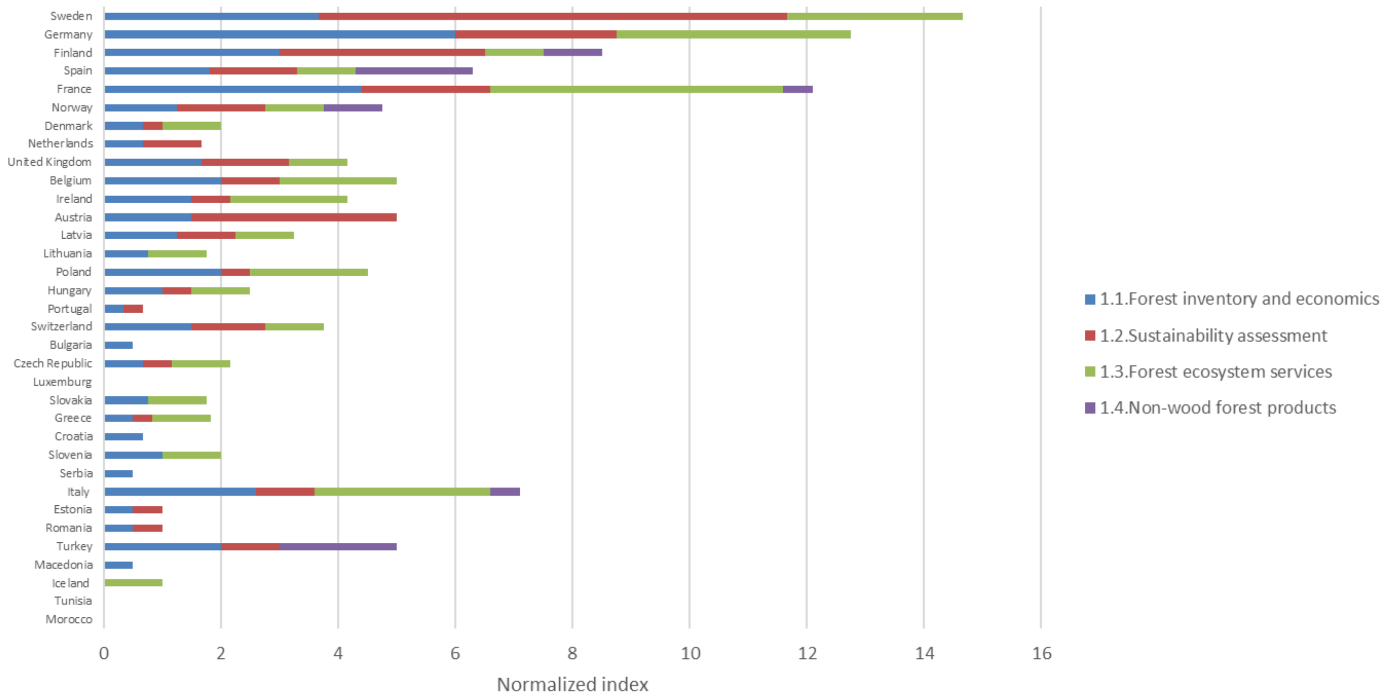

Figure 3. Capacity of organizations by country in forest systems

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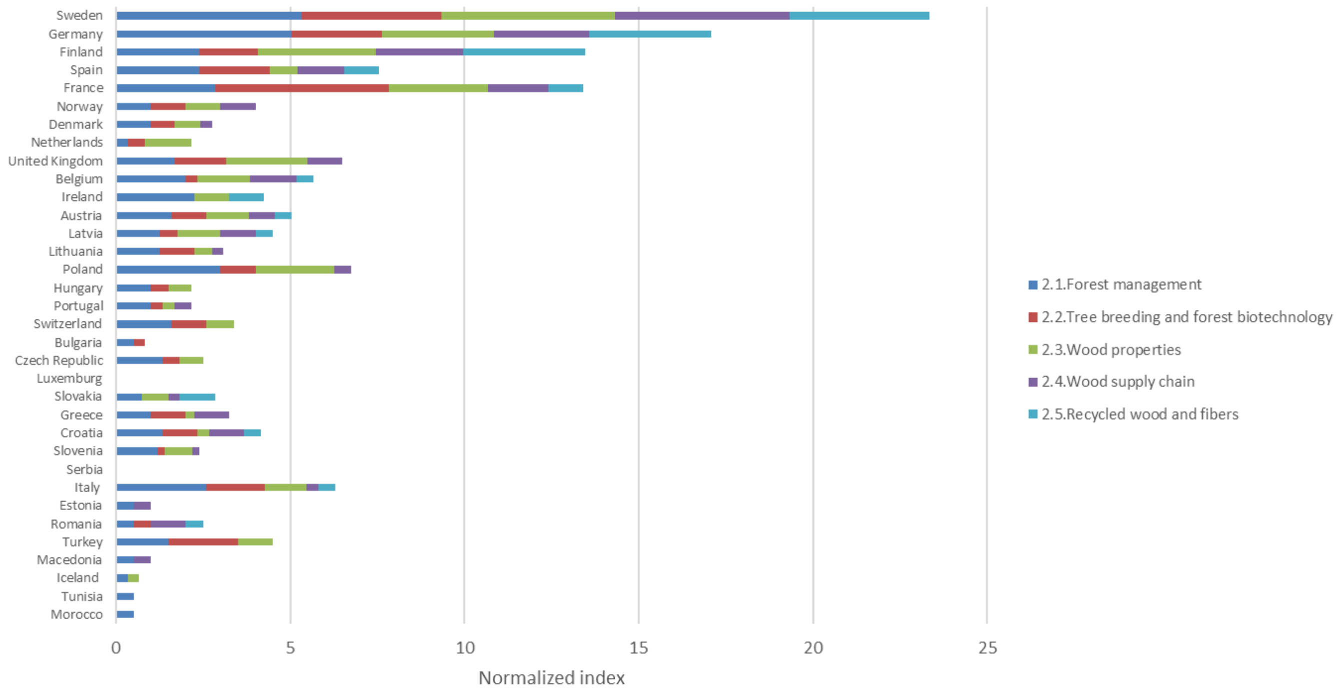

Figure 4. Capacity of organizations by country in Forest biomass & raw materials

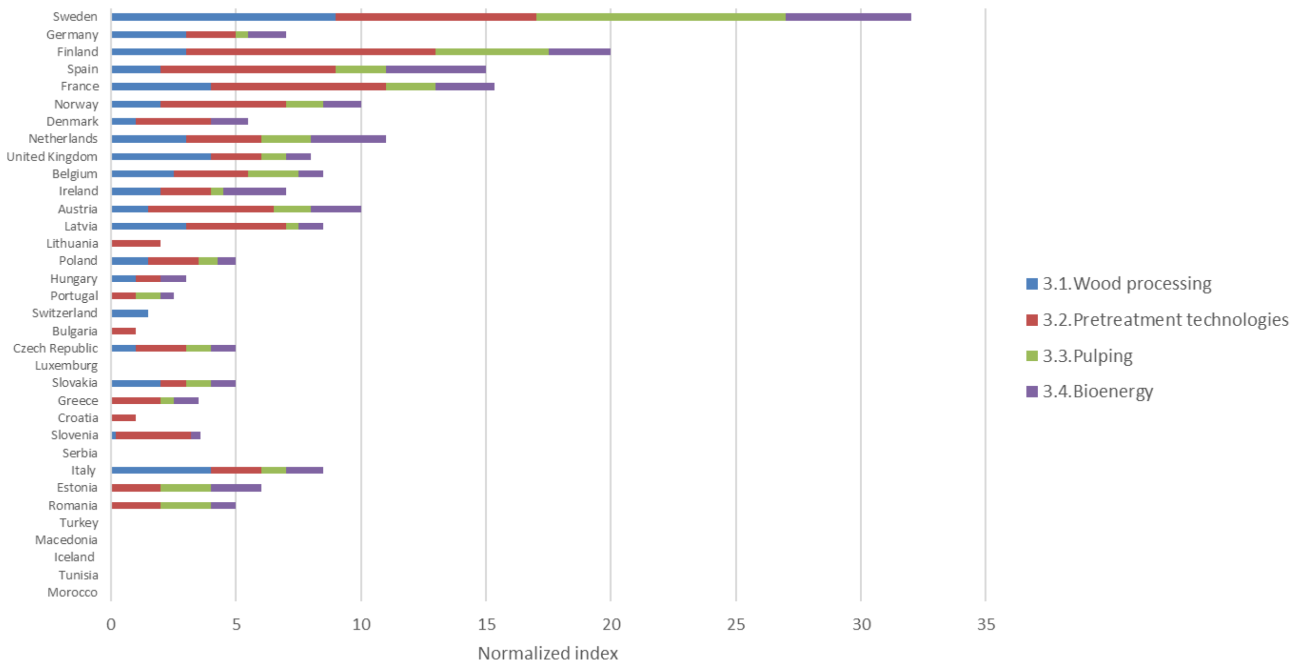

Figure 5. Capacity of organizations by country in Primary processing

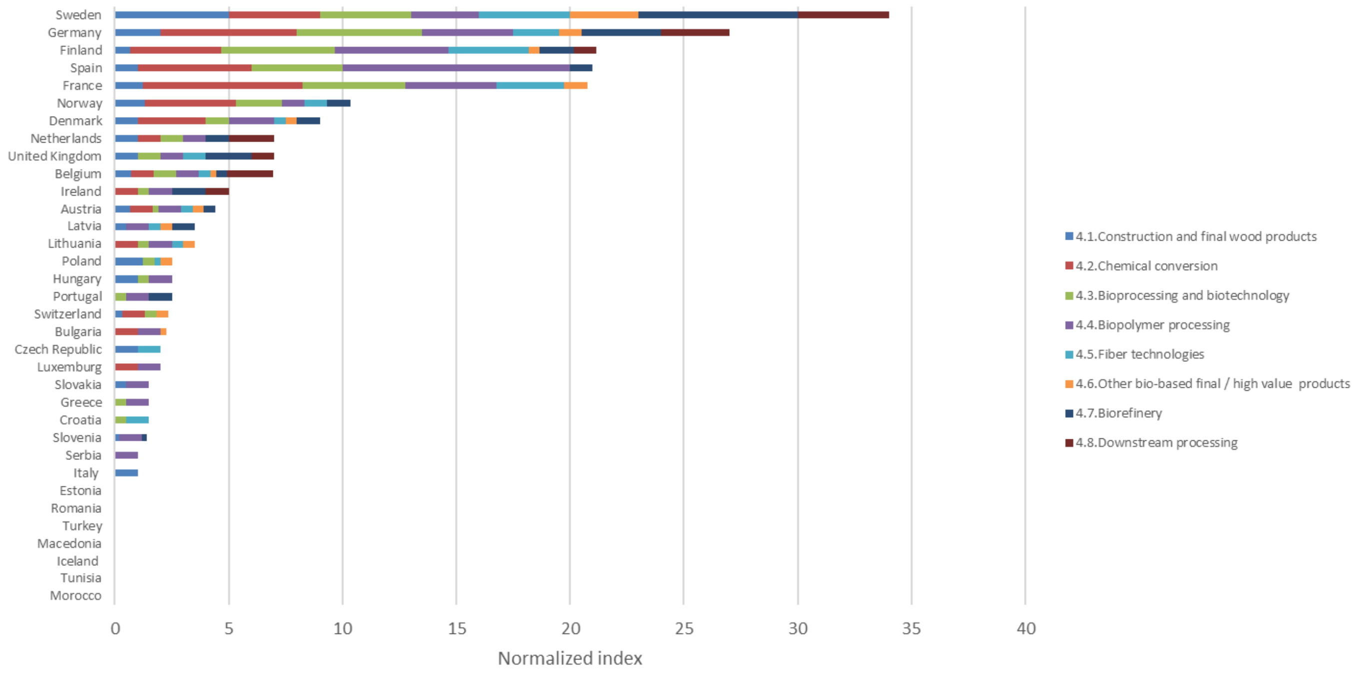

Figure 6. Capacity of organizations by country in Secondary processing

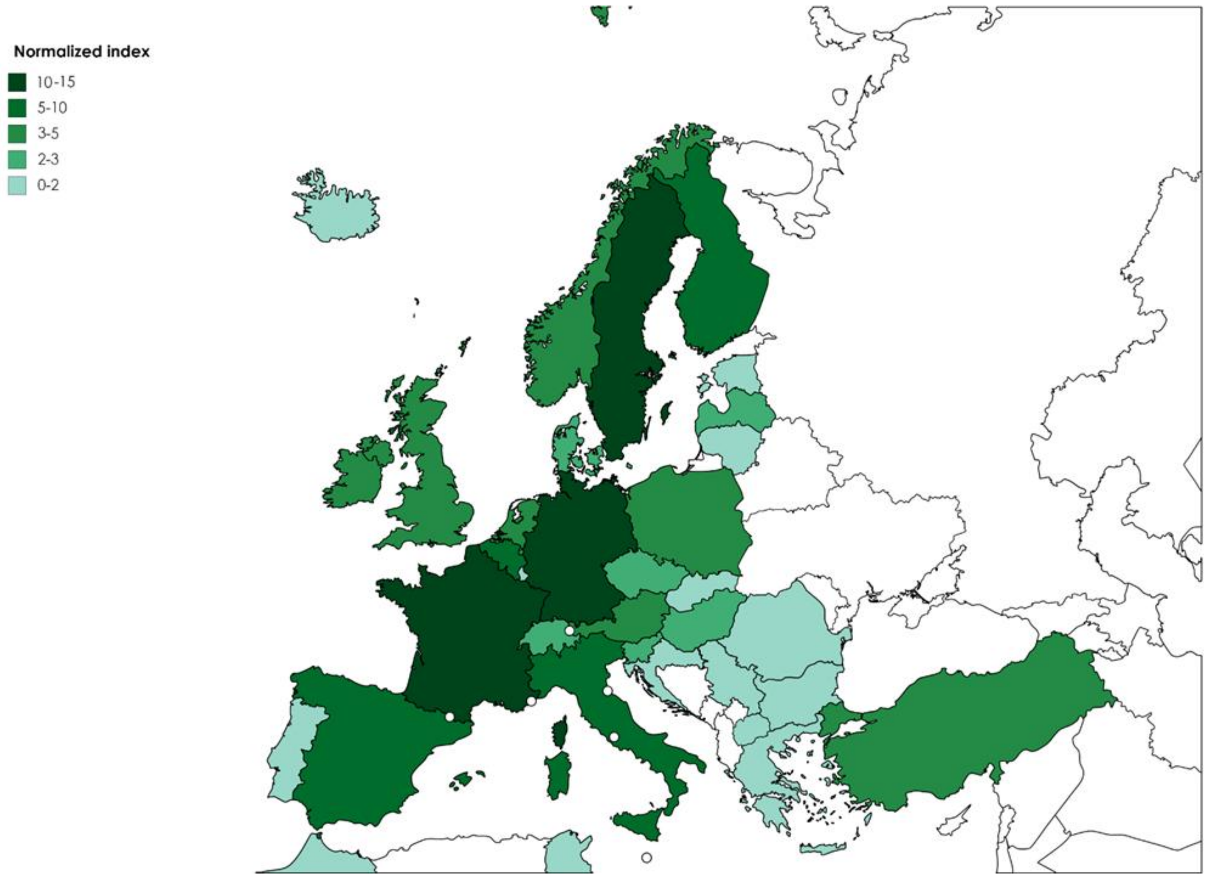

Figure 7. Capacity of organizations by country in forest systems – map

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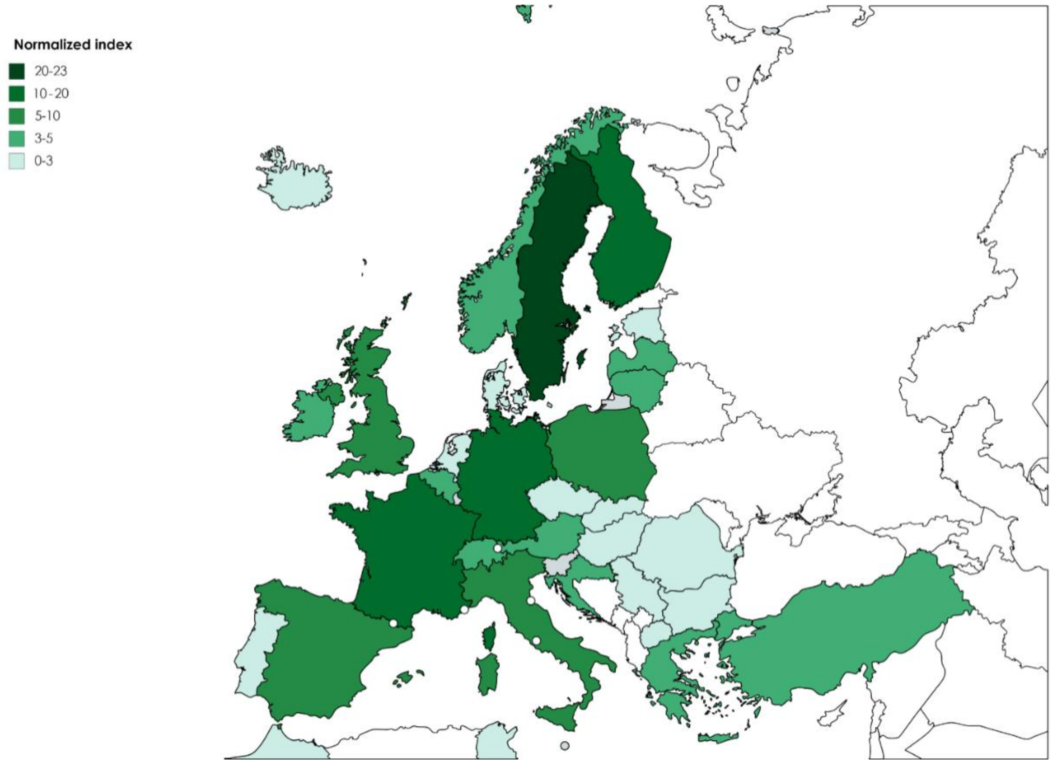

Figure 8. Capacity of organizations by country in Forest biomass & raw materials– map

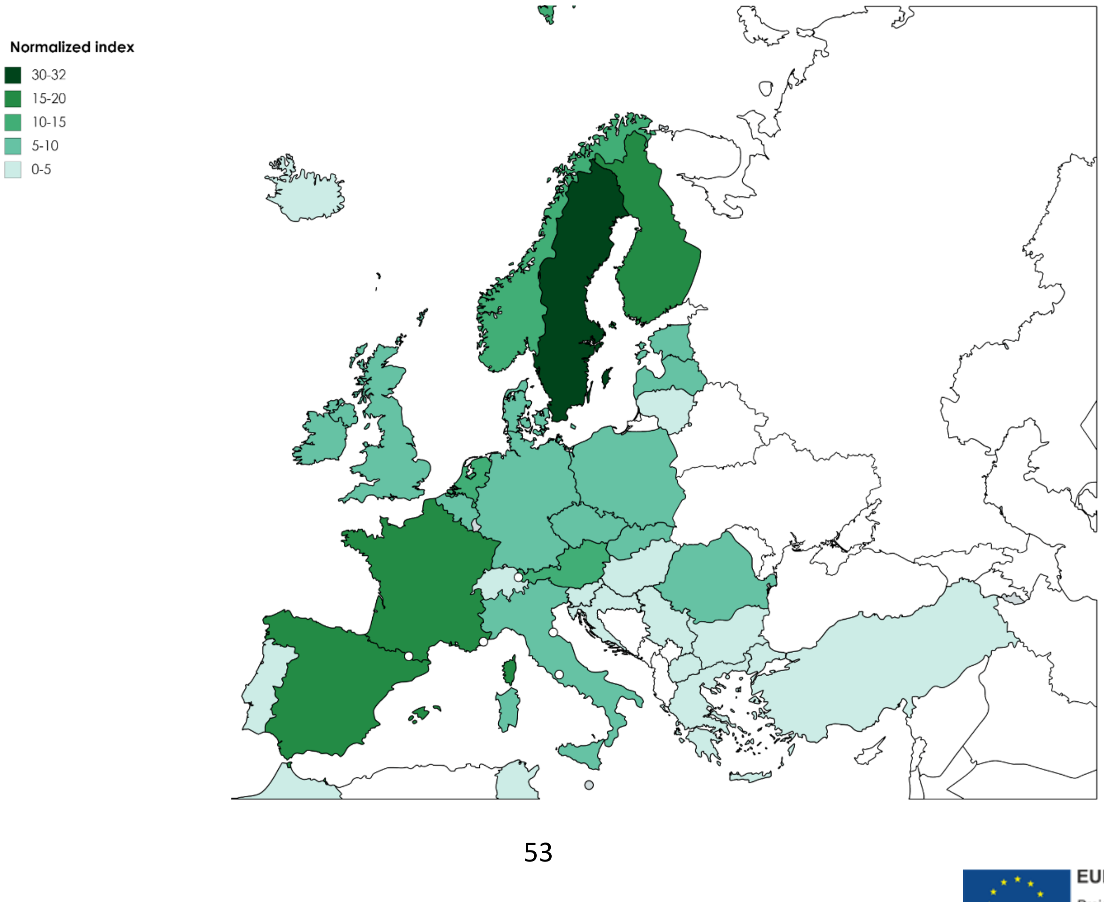

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Figure 9. Capacity of organizations by country in Primary processing– map

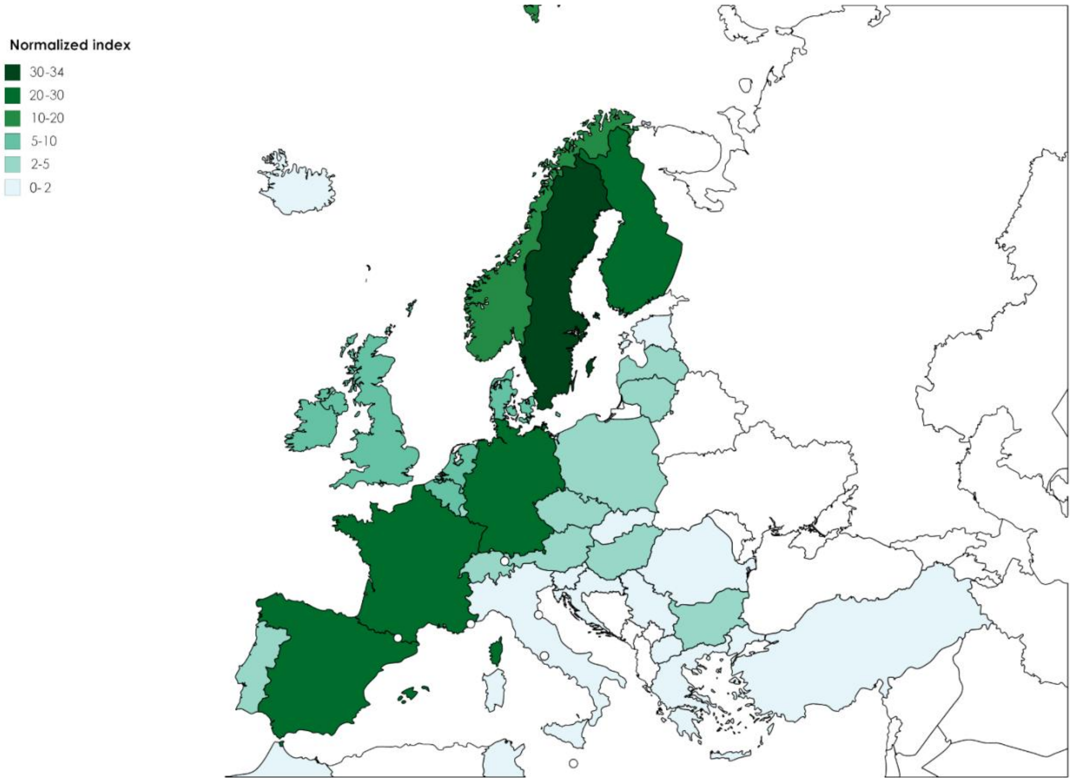

Figure 10. Capacity of organizations by country in Secondary processing– map

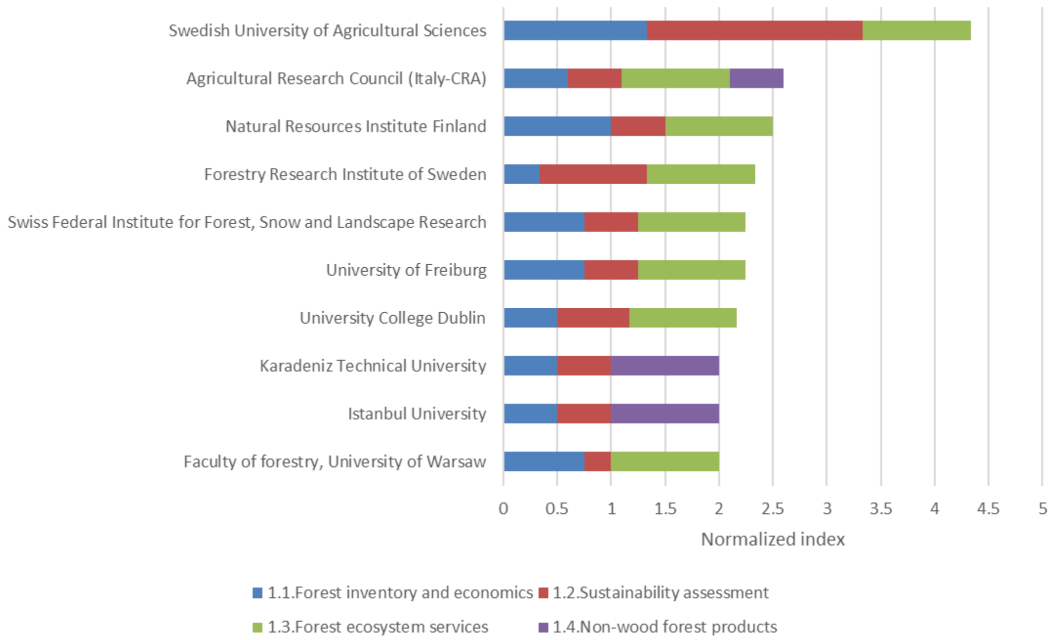

Figure 11. Top 10 organizations in Forest systems

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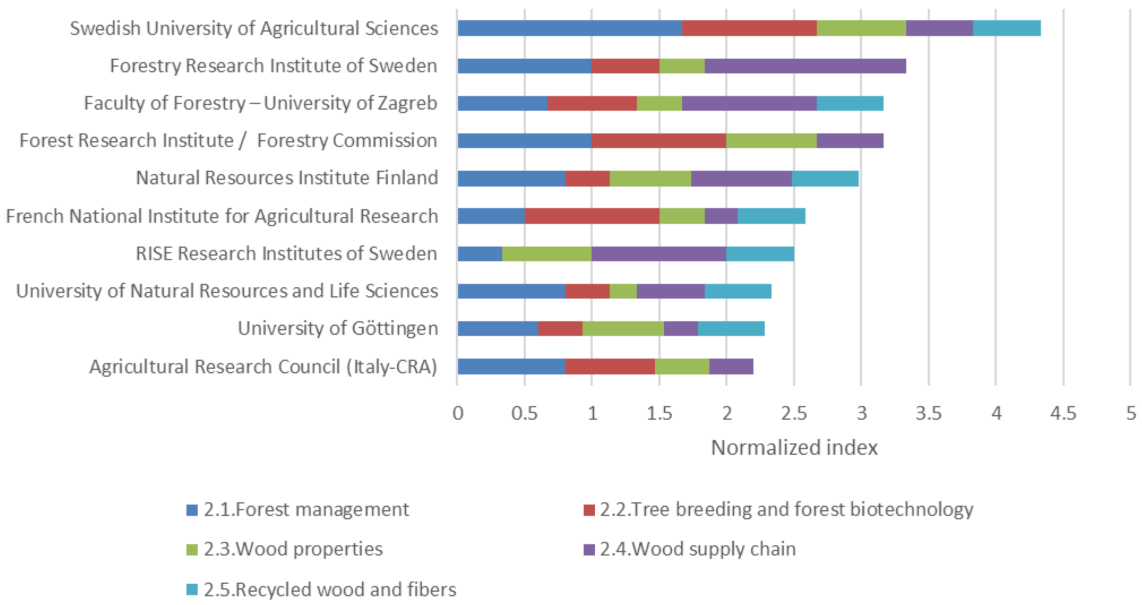

Figure 12. Top 10 organizations in Forest biomass & raw materials

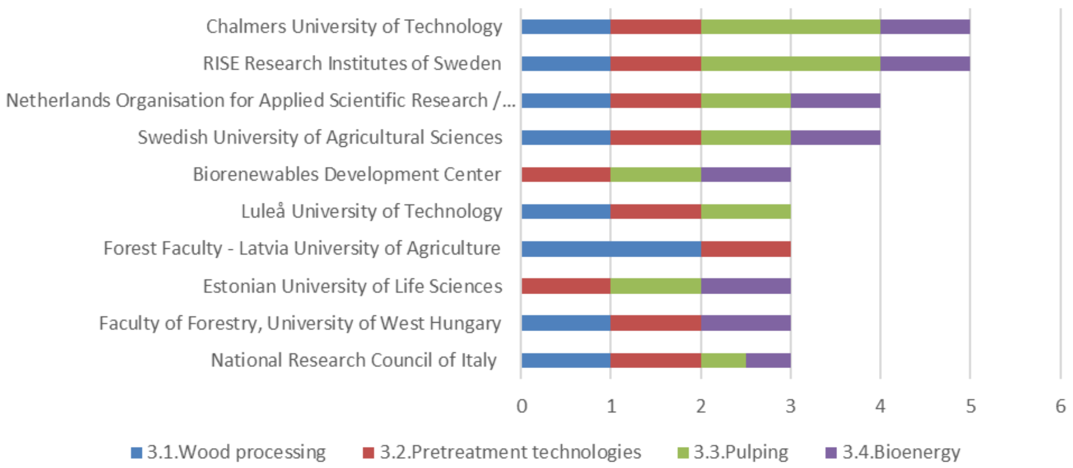

Figure 13. Top 10 organizations in Primary processing

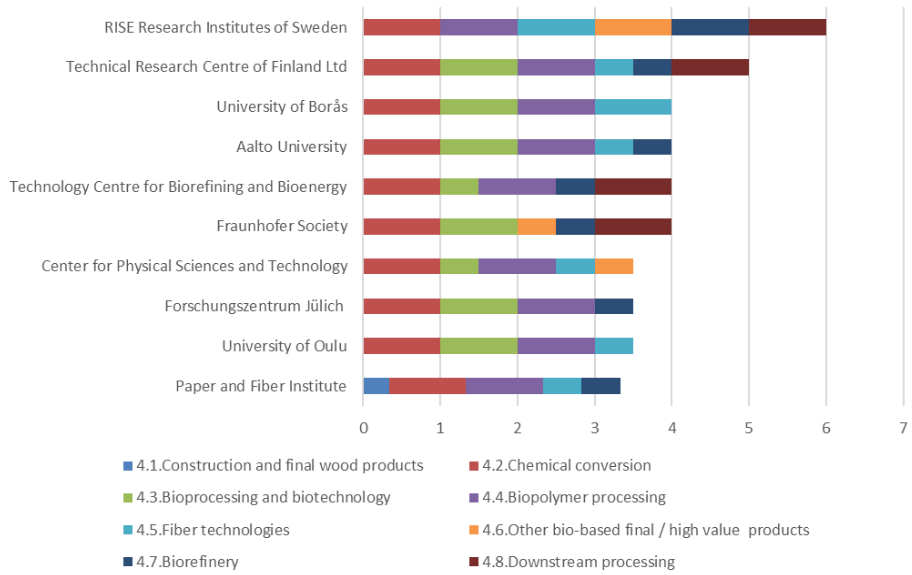

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Figure 14. Top 10 organizations in Secondary processing

Appendix III. Additional results from the mapping of research activities in forest bioeconomy

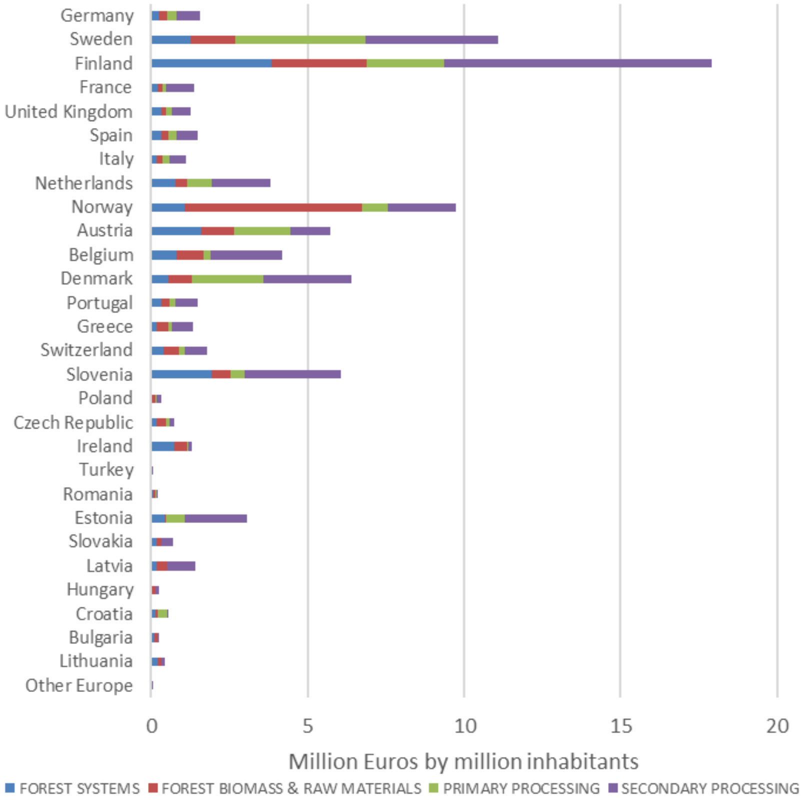

Figure 1. EC's funding by population and category

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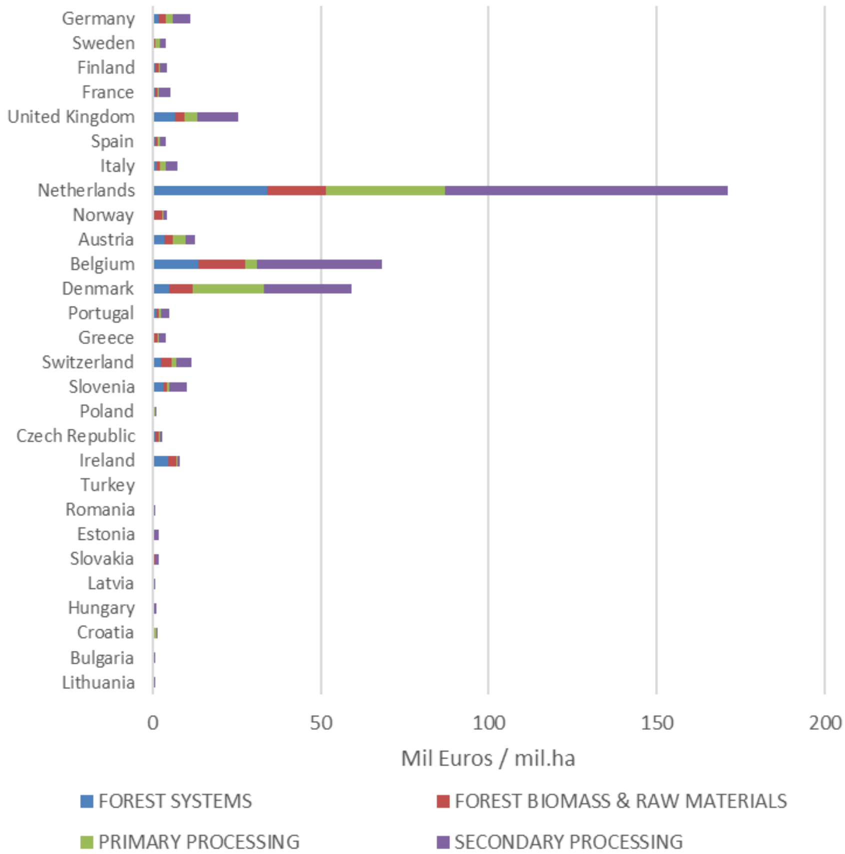

Figure 2. EC's funding by country and forest area

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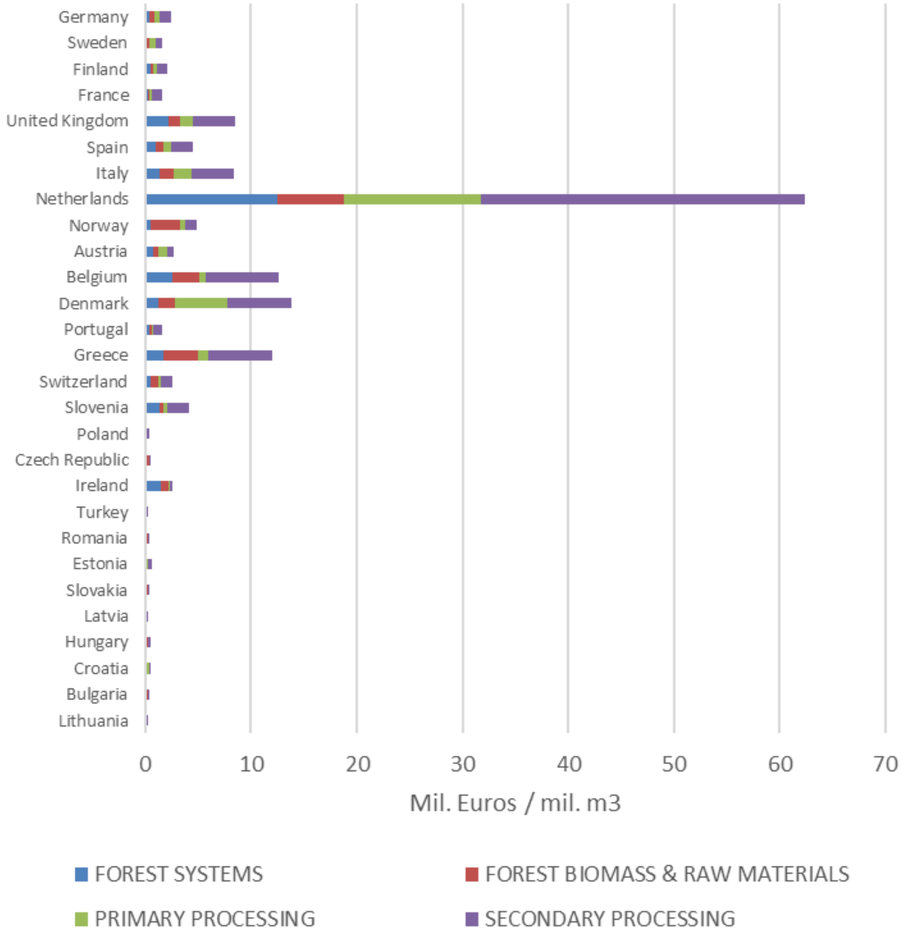

Figure 3. EC's funding by country and removals

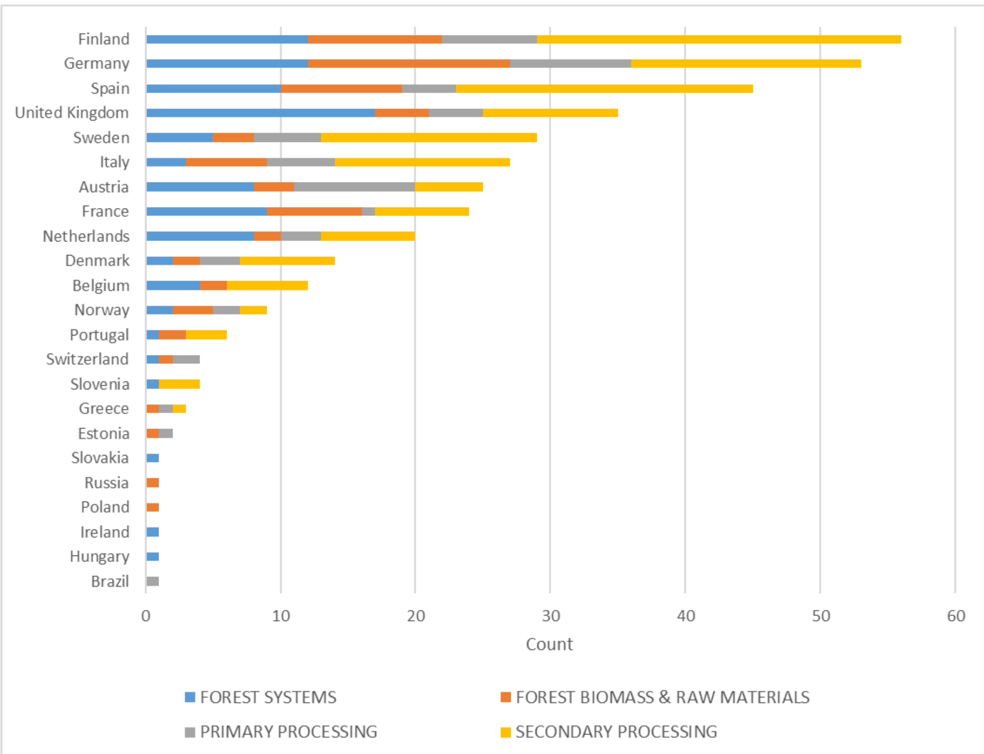

Figure 4. Number of instances when an organization was a coordinator in a project by country

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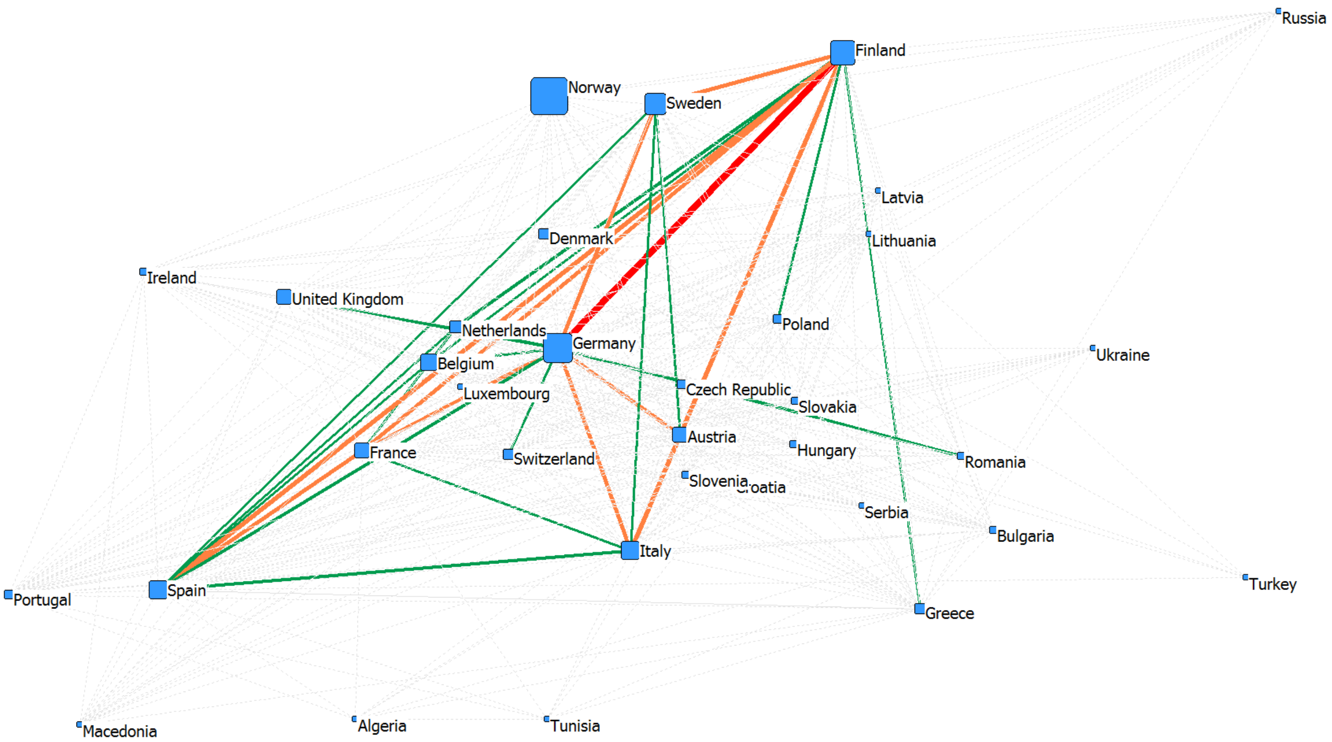

Figure 5. Collaboration between countries in Forest biomass & raw material

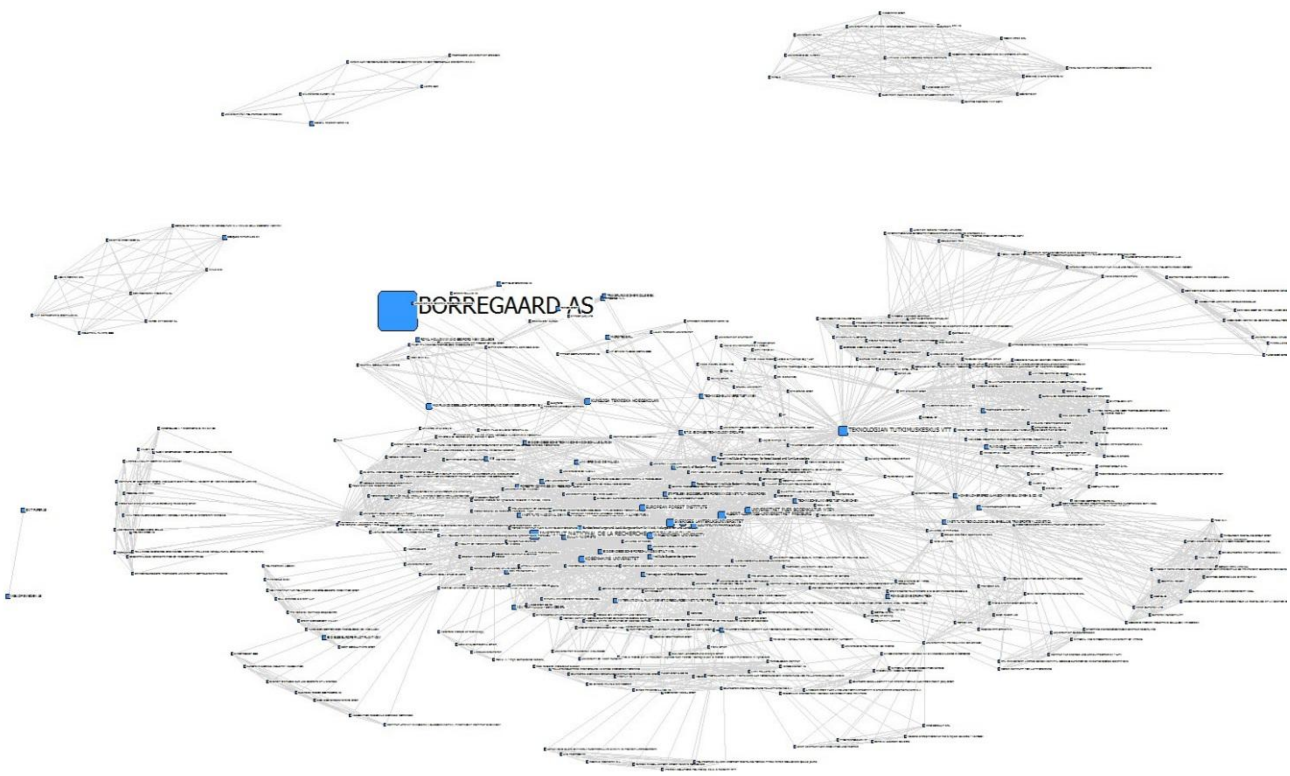

Figure 6. Collaboration between organizations in Forest biomass & raw material

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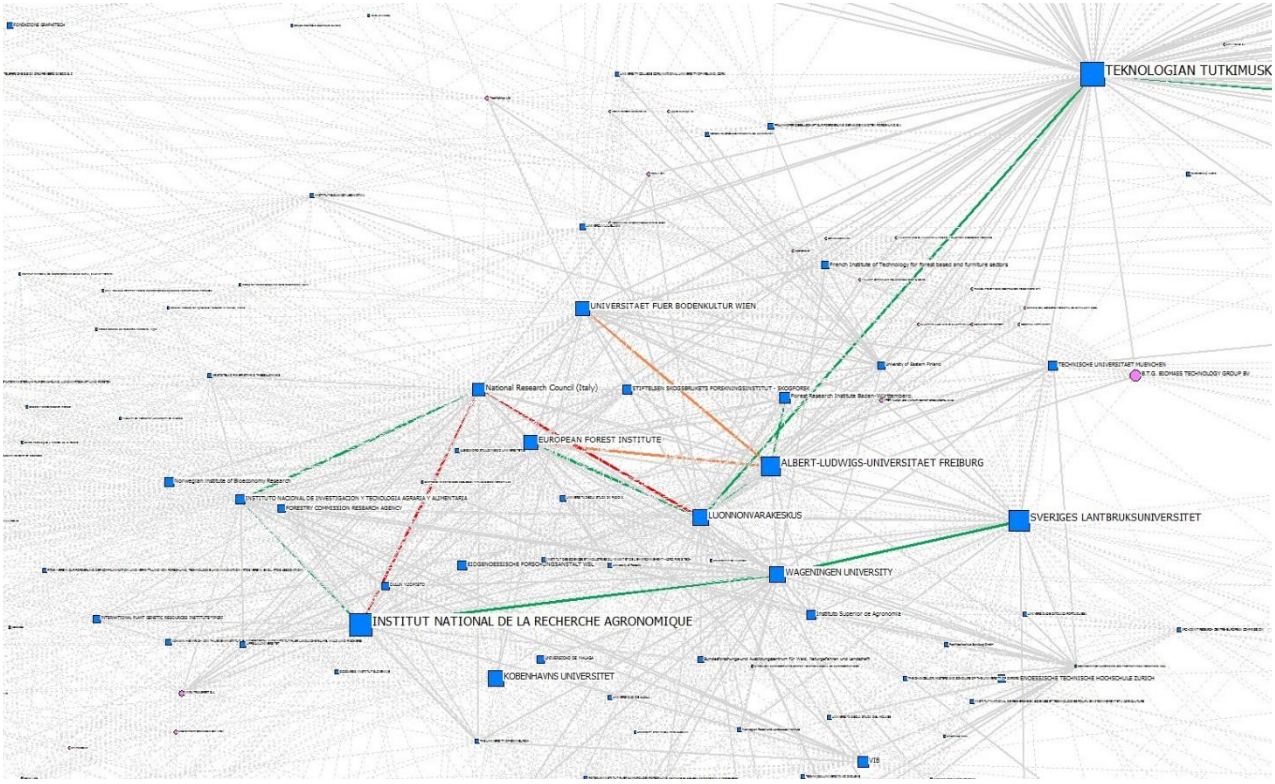

Figure 7. Collaboration between organizations in Forest biomass & raw material – zoom to centre

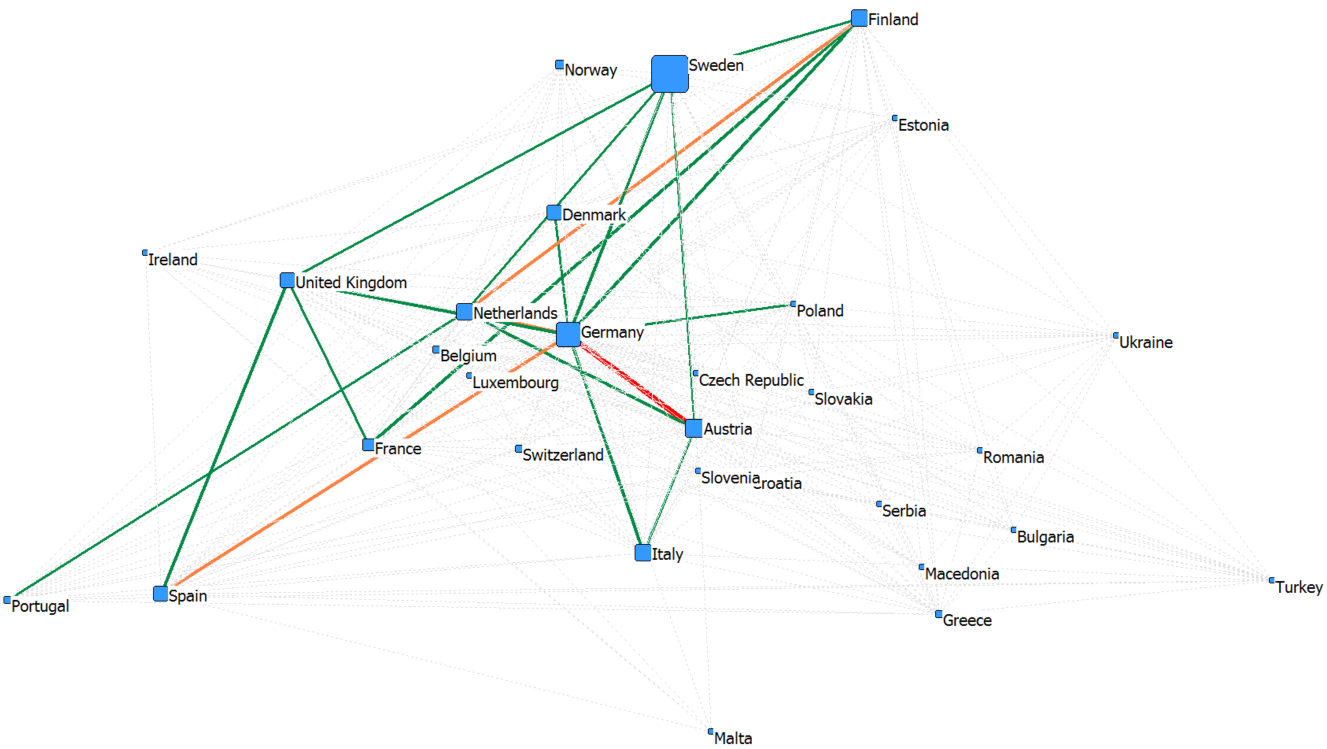

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Figure 8. Collaboration between countries in Primary processing

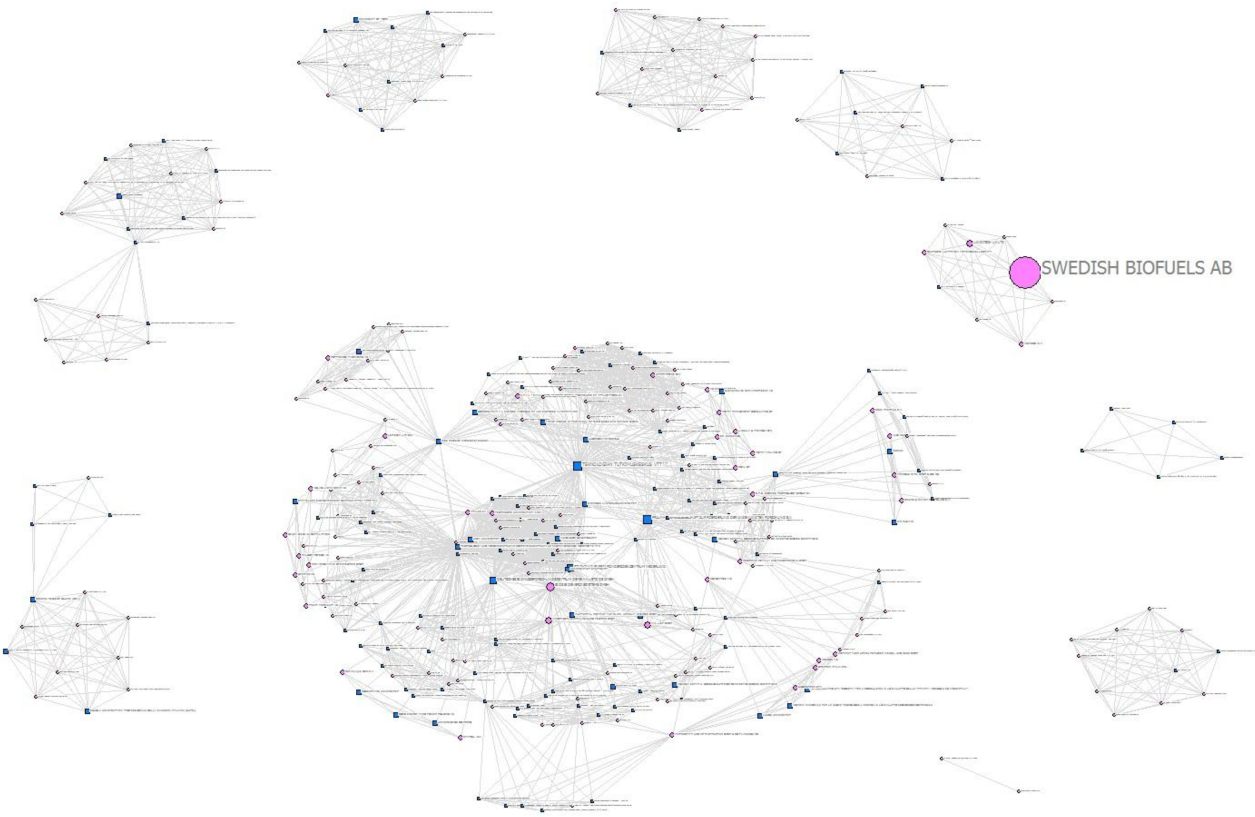

Figure 9. Collaboration between organizations in Primary processing

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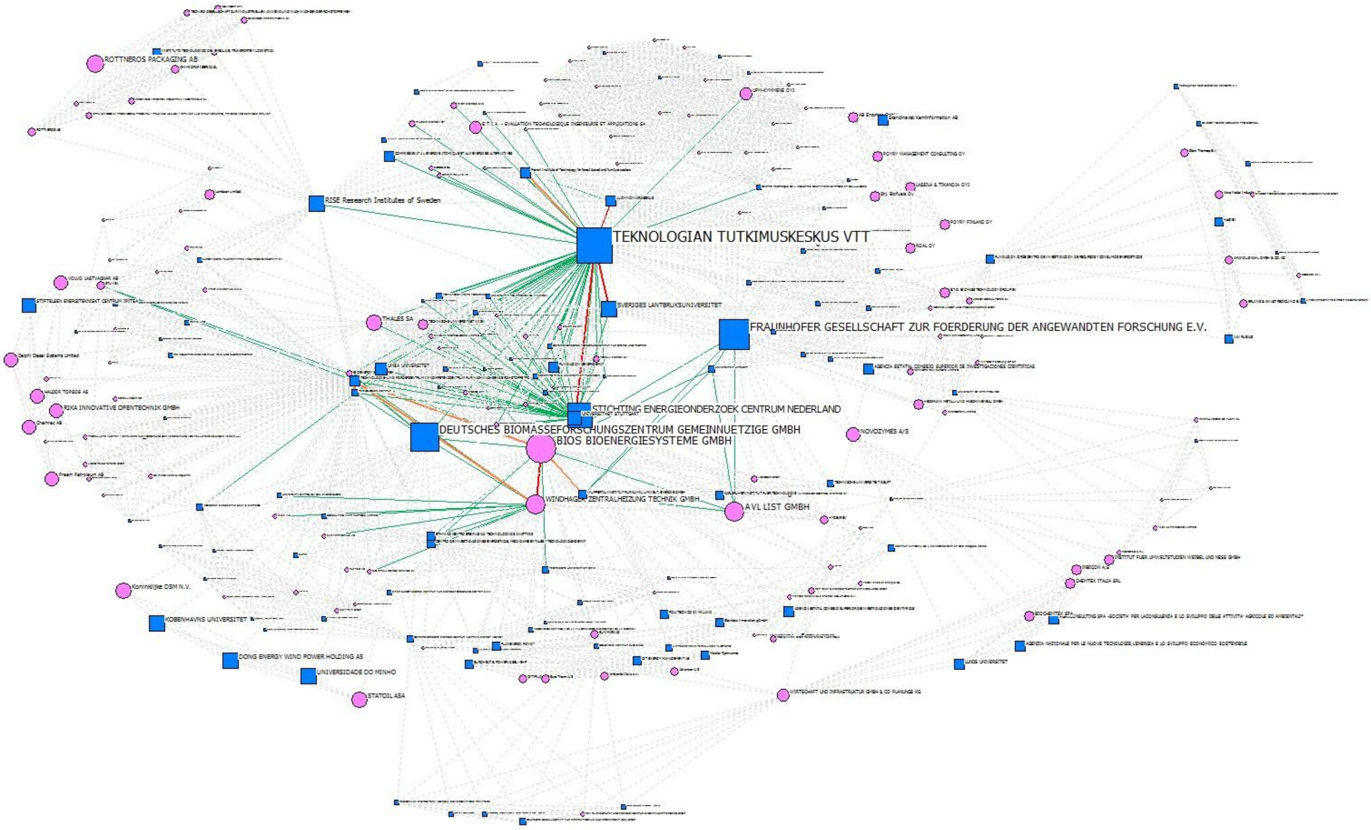

Figure 10. Collaboration between organizations in Primary processing – zoom to centre

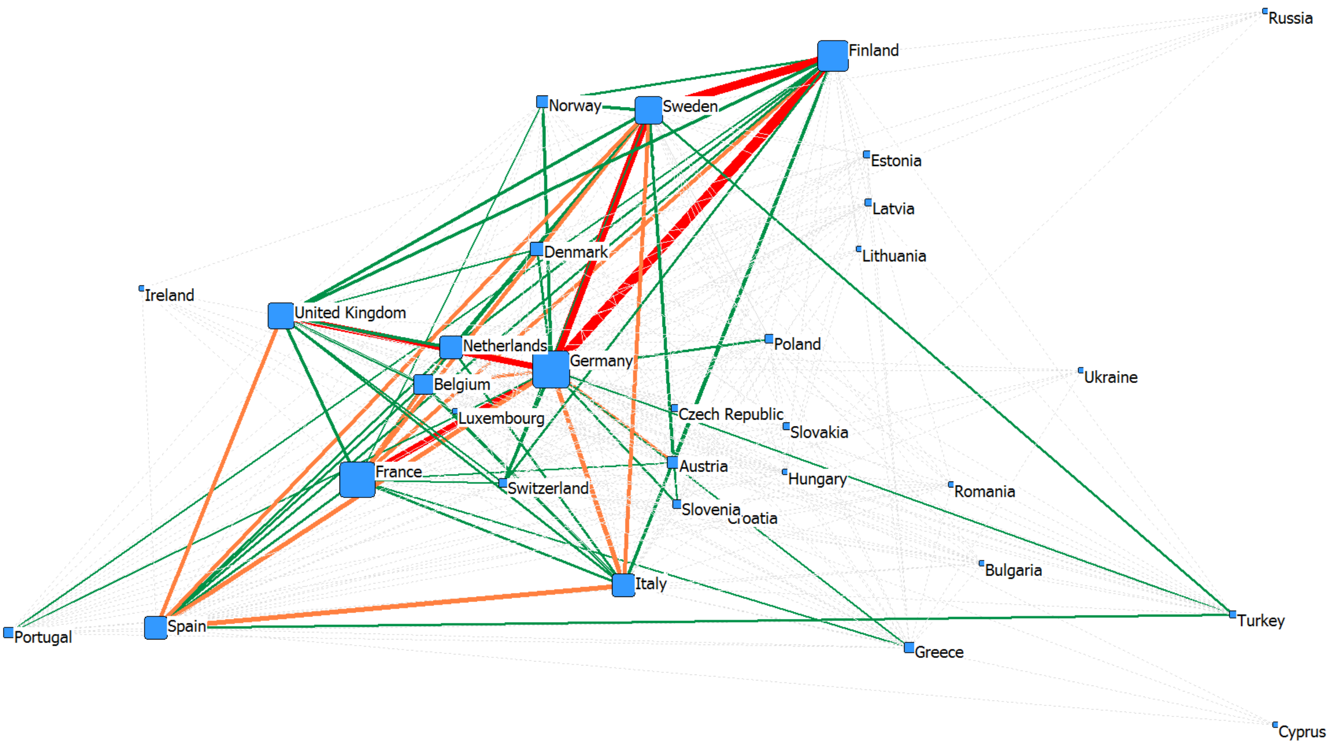

Figure 11. Collaboration between countries in Secondary processing

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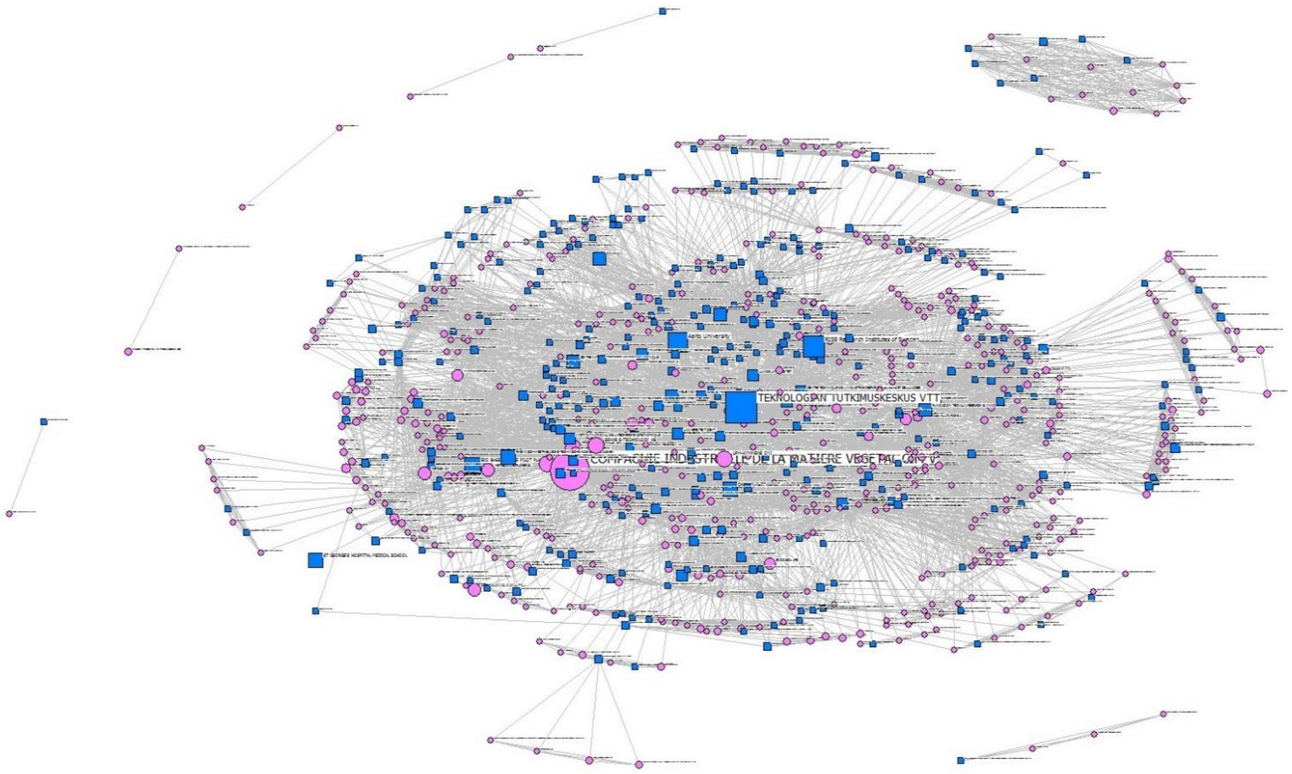

Figure 12. Collaboration between organizations in Secondary processing

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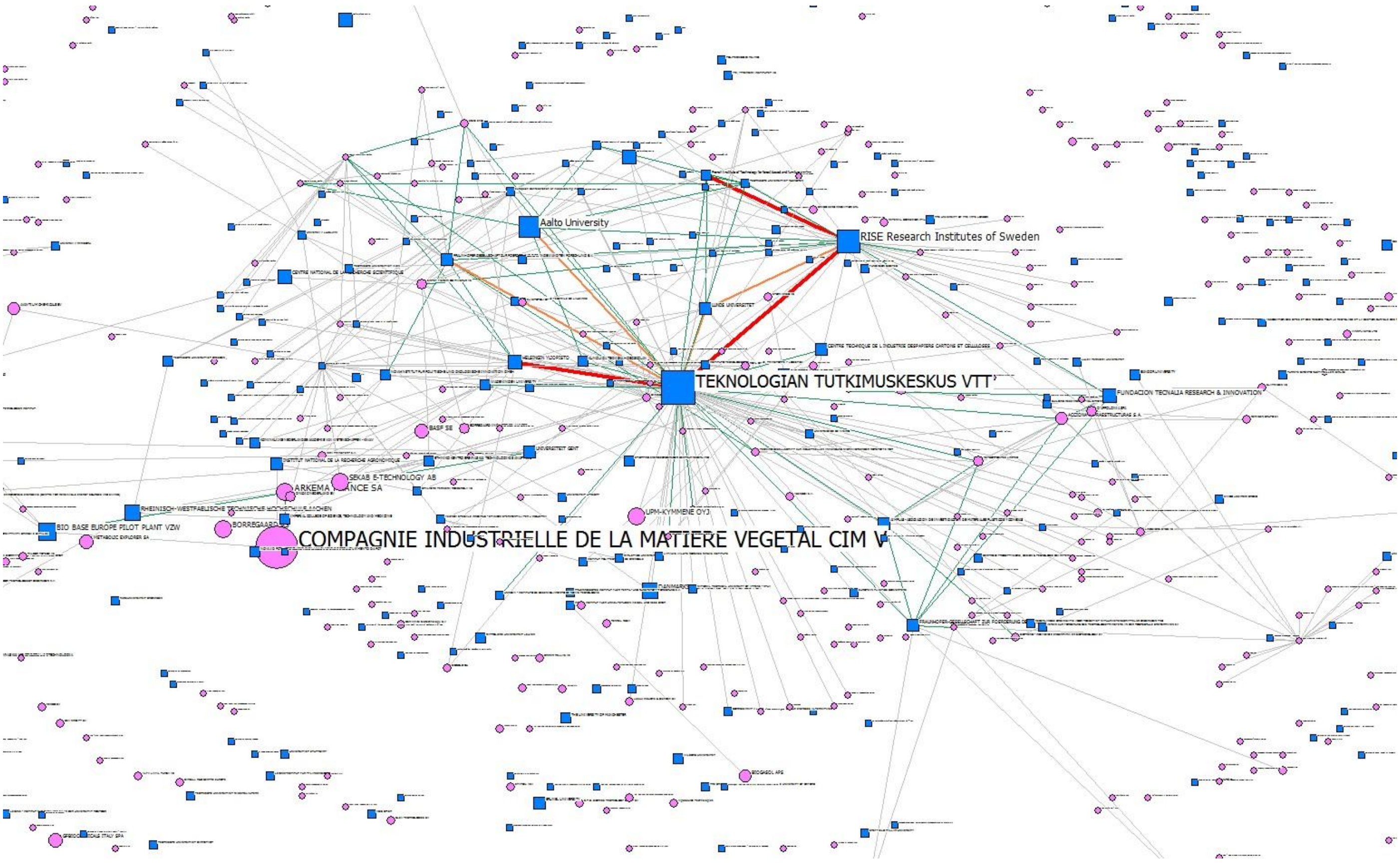

Figure 13. Collaboration between organizations in Secondary processing - zoom to centre

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