# Appendix – Data extraction and measurement

The data used to build up the analysis has been taken either from French national project [FORGECO 2014], European project [ARANGE 2015], or literature about the case study from a search in the Scopus data base; for more information about the source of data, see table (S1). FORGECO project aimed to develop a territorial forestry approach based on the principles of integrated management of ecosystems that can accompany and organize the increase in harvesting of the resource and better preservation of biodiversity and soil quality. There were one mountain forest case study approached, Quatre-Montagne forests. The survey focuses on the participatory and adaptive approach to forest management expertise and its ecological and socio-economic vulnerabilities, and the development and evaluation of scenarios for intensifying forest management. In order to allow spatial and temporal integration of information and to support decision-making process, the project is based on the construction of decision-making tools, each of which possesses a generic character: (i) model resource dynamics and mobilization (ii) habitat quality model (iii) scenario analysis using the production boundary method, (iv) resilience and scenario viability analysis, (v) participative approach structured by the method of the territory game [Lardon et al. 2016]. Moreover, ARANGE project [Bugmann et al. 2017] objective was to analyze the multifunctional forest management for several case studies in Europe (seven mountain forests across Europe; Montes de Valsain (Spain), Quatre-Montagne (France), Montafon (Austria), Sneznik (Slovenia), Vilhelmina (Sweden), Kozie Chrbty (Slovakia), Shiroka Laka (Bulgaria)). This scientific synthesis integrated the findings from generic and case study specific analysis to develop a web-based decision support tool box for multifunctional mountain forest management to support interested stakeholders beyond the time span of the project. The main bases for the project are (i) the use of regional case studies, (ii) stakeholder's involvement in the analysis, (iii) the use of models and tools to predict forest conditions and assess ecosystem services, and (iv) establishing new plans and decisions support tools.

The processes of diagnosing important SES framework variables were conducted by the following steps:

1- Identify the main component of the Quatre-Montagne forest SES (governance system, resource units, resource system, and users).
2- Describe the natural variables that affect each of the forest functions and eventually the governance revolving around them.
3- Identify the general action situation in which the functions interact.
4- Explore the links and relations between governance and forest functions' performance.

These four steps require figuring out which variables from the SES framework are essential and descriptive. Using the data collected, we use two types of assessment methods for variables' importance:

1- The assessment of the variables from the literature and reports (found in table S1) of the projects depending on the language of the text in which they are described in (see assessment in table S1).
2- Authors' knowledge and expertise on the case study, which determine the variables and infrastructures that are most relevant to the function

As mentioned in the main text, the qualitative comparisons that describe the variables in the SES framework (moderate, strong, high, low) are relative to other mountain forests studied by the ARANGE project. For this, we mention that these case studies are already compared with each other within the text's language of analysis and studies of the ARANGE project.

Moreover, building on the description offered by the SES framework analysis, we constructed the robustness framework analysis by describing its conceptual map for every forest function, essentially through identifying the main components of the robustness framework and characterizing their interactions. Furthermore, the importance of types of infrastructures for each forest function (+, ++, and +++) is measured by the criteria described above as well. We give the following examples to facilitate the assessment comprehension:

- We conclude through the SES framework's analysis that accessibility is a main issue for the wood production function (see variable I5-infrastructure investment activities and RS4-human constructed facilities), which implicates that hard human-made infrastructures, which are mainly composed of roads, are of a great importance for the function. This implies the +++ measure.

- Variables A6 (norms/social capital), A7 (Knowledge of the SES), O1 (social performance measures) suggest that nature conservation requires a lot of social capital to function and develop implying the importance of soft-human made infrastructures, which are presented by a set of rules. This implies the +++ measure.

- Variable I2 (Information sharing) advocates that the web of relations between forest function actors are important to increase the performance of the nature conservation function, which implies the importance of social infrastructures. Although the hard-human made infrastructure is important, one can qualitatively evaluate through author's expertise and literature language that the infrastructure is not as important as the norms and rules (soft-human made infrastructure) for the performance of nature conservation. This implies the ++ measure.

Table S1. A table presenting the relevant SES framework variables, their assessment method, and the data used to for the assessment method (source of data and type of study)

| Data used for assessment / Variable | Source (type of study) | Assessment |
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| RS1 – sectors | Mountain areas in Europe 2004 (Reports), FORGECO 2014 (French national project), ARANGE 2015 (European project) | These projects highlighted the different functions and their importance (tourism, wood production, and forest conservation), and as such, they studied the multifunctional forest management shedding light on the different conflicts that arise between them. |
| RS2 – clarity of system boundaries | Tissot and Yann 2013 (Report) | This reference analyzed the forest policy in France, explaining the property rights of owners including their property boundaries. |
| RS3 – size of resource system | FORGECO 2014 (French national project), ARANGE 2015 (European project), Tenerelli et al. 2016 (Article) | The projects clearly defined the size of the forest through spatial measurements and field work. |
| RS4 – human constructed facilities | Achard 2011 (Report), FORGECO 2014 (French national project) | The references clearly stated the different human built facilities in the forest (saw mills, roads, resorts, hotels, etc.) |
| RS5 – productivity of the system | FORGECO 2014 (French national project) | The project presented the different tree species found in the forest (e.g., Norway Spruce, silver fir, European beech) and discussed their abundance in the public and private forests |
| RS7 – predictability of the system dynamics | FORGECO 2014 (French national project), ARANGE 2015 (European project), Mathias et al. 2015 (Article), Lardon et al. 2016 (Book chapter) | Mathias et al. [2015] builds a mathematical model based on empirical biophysical data for the forest growth (data includes: tree regeneration, competition between small and big trees, mortalities, light interception, tree diameters, deadwood and biodiversity, etc.). The article also tests different wood removal scenarios and predicts their impact on the forest. Moreover, FORGECO [2014] and ARANGE [2015] also analyze different multifunctional forest management scenarios predicting their impact on the forest as well as on the performance of other functions through diverse methods [e.g., method of territory game] |
| RS9 – location | Avocat et al. 2012 (Article), FORGECO 2014 (French national project), ARANGE 2015 (European project), Mathias et al. 2015 (Article), Lardon et al. 2016 (Book chapter), etc. | The Quatre-Montagne forest is located in the Grenoble agglomeration, at borders between northern and southern French Alps with a mountainous location |
| GS1 – government organizations | Kouplevatskaya-Buttoud 2009 (Article), Tissot and Yann 2013 (Report), Sarvasova et al. 2014 (Article), ARANGE 2015 (European project) | The references suggest high presence of government organizations. All exploitation activities are referred to legal license and documents issued by government organization. For example, the ONF (National Forestry Office) is one of the important government organizations with authority overlapping on regional, departmental, and communal levels. |
| GS2 – nongovernment organization | Tissot and Yann 2013 (Report), FORGECO 2014 (French national project), Sarvasova et al. 2014 (Article) ARANGE 2015 (European project) | The sources clearly outline the different nongovernmental organizations that interplay in the Quatre-Montagne, which ranges from organizations with exploitation and recreational objectives to organizations with nature conservation objectives. In addition, Sarvasova et al. [2014] assesses the contribution of such |

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| | | NGOs to the application of multifunctional forest management |
| GS3 - network structure | Tissot and Yann 2013 (Report), FORGECO 2014 (French national project), ARANGE 2015 (European project), Kouplevatskaya-Buttoud 2009 (Article) | The network structure is described as a top-down complex network with different governmental and nongovernmental organizations interacting on three different levels. Figure 2 in the main text explains the different levels of government organizations and the documents that are issued at each level. |
| GS4 - property rights systems | Tissot and Yann 2013 (Report) | Forest property rights are well known through a legal system determined by the French government. Nonetheless, Despite the efforts of property consolidation via exchange fairs or via the law, changes are slow. Forest is a property that is seldom exchanged. |
| GS5 - operational rules | Achard 2011 (Report), Tissot and Yann 2013 (Report), ARANGE 2015 (European project), FORGECO 2014 (French national project) | Operational rules are clearly defined through a legal system that gives licenses based on exploitation constraints |
| GS6 - collective choice rules | Tissot and Yann 2013 (Report), ARANGE 2015 (European project), Kouplevatskaya-Buttoud 2009 (Article) | Defined by the French decentralization system, local communities admit an increasing role in defining the rules for exploitation in the Quatre-Montagne, mainly though the CCMV (community of communes of the Vercors massif). |
| GS8 - monitoring and sanctioning rules | Tissot and Yann 2013 (Report), ARANGE 2015 (European project) | The monitoring of French forest policy is a very important task. Various instruments are designed to evaluate and monitor national and regional processes, and programs established by the government. |
| RU1 - resource unit mobility | Avocat et al. 2012 (Article), FORGECO 2014 (French national project), ARANGE 2015 (European project), Mathias et al. 2015 (Article), Lardon et al. 2016 (Book chapter), etc. | As trees are the main producer of wood and reinforce of recreation and conserver of nature in the forest, the resource unit (trees) are non-mobile. However, the growth and height of trees varies depending on the different elevations in the forest |
| RU2 - growth and replacement rate | FORGECO 2014 (French national project), ARANGE 2015 (European project), Mathias et al. 2015 | Studies and dynamical models presented by both projects that analyze the replacement rates of trees, and analyze the different growth of trees depending on the elevation. These references refer to high growth of forest with respect to other forests in Europe |
| RU4 - economic value | Achard 2011 (Report), FORGECO 2014 (French national project), ARANGE 2015 (European project) | Studies the economic values of wood, deadwood, and fuel wood in the forest that are considered with a high value in the French market |
| RU7 - spatial and temporal distribution | FORGECO 2014 (French national project), ARANGE 2015 (European project) | In the projects, specific importance is given to the spatial distribution of trees with focused study on the effect of tree elevation on the growth of trees |
| A1 - number of relevant actors | Mountain areas in Europe 2004 (Reports), Tissot and Yann 2013 (Report), FORGECO 2014 (French national project), ARANGE 2015 (European project) | The references discuss the importance of forest with an implication to the high touristic attractions in the area, which allows for the development of the industry. Moreover, the forest has a lot wood production actors in relative to its size |
| A4 - location | FORGECO 2014 (French national project), ARANGE 2015 (European project) | The close proximity of the forest to the agglomeration of Grenoble (a main city in France), has allowed for the development of tourism as an important economic driver |
| A6 - norms/ social capital | Mountain areas in Europe 2004 (Reports), FORGECO 2014 (French national project), ARANGE 2015 (European project) | Conflicts arise in the forest with different objectives. The references reported two preferences of the different actors: Tourism and nature conservation (with a preference of conservation), wood removal (with a preference of harvest) |
| A7 - knowledge of SES/ mental models | FORGECO 2014 (French national project), ARANGE 2015 (European project) | The projects did many studies and conceptual approaches to anticipate and gather information about the Quatre-Montagne forest SES |
| I1 - harvesting levels | Achard 2011 (Report), FORGECO 2014 (French national project), ARANGE 2015 (European project), | On one hand, harvesting levels for wood production are reported to be high with respect to other European mountain forest case studies approached with the project. On the other, the Quatre-Montagne forest is |

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| | | considered one of the most visited destinations for winter tourism. Moreover, the forest belongs to one of the most preserved ecosystems in Europe. Finally, infrastructure protection strategies are being used in the area |
| I2 - information sharing | FORGECO 2014 (French national project), ARANGE 2015 (European project) | Information sharing is an important aspect in the Quatre-Montagne and usually happen inside meetings and local chamber, one of which is the community of communes of Vercors massif (CCMV) |
| I4 - conflicts | Gonzales-Redin et al. 2015 (Article), FORGECO 2014 (French national project), ARANGE 2015 (European project), Lafond et al. 2017 (Article) | Conflicts are highly reported especially between the main forest functions: tourism, wood production, and nature conservation |
| I5 - infrastructure investment activities | Achard 2011 (Report), FORGECO 2014 (French national project), ARANGE 2015 (European project) | Infrastructure provision is a main issue in the Quatre-Montagne forest. On one hand, roads exhibit many negative impacts on scenic beauty and the ecosystem (i.e., implication with an impact on nature conservation function). On the other hand, and in the presence of accessibility problems, roads are essential for the development of forest functions, especially wood production function. European union offer a lot of subsidies directed towards development of infrastructure (which are mainly roads) |
| O1 - social performance measures | Kouplevatskaya-Buttoud 2009 (Article) | Social performance is demonstrated in the sustained and increasing role of communal role in the collective action within the forest |
| O2 - ecological performance measures | Onida 2009, Avocat et al. 2012, FORGECO 2014 (French national project), ARANGE 2015 (European project) | Legal application and management strategies has allowed for the sustainability of the forest and its resilience. Although climate change has made a huge impact on tourism performance due to the scarcity of snow (winter tourism), the government and management entities has limited this impact through the deployment of snow canons in the mountain ranges |
| ECO1 - climate change | European Observatory of Mountain forests 2009 (Reports), Bugmann et al. 2017 (Article), | Climate change has reported to have impacts on the forest system, with a great implication to the snow melting in the mountains |
| S1 - economic development | FORGECO 2014 (French national project), Sarvasova et al. 2014 (Article), ARANGE 2015 (European project), Bugmann et al. 2017 (Article) | These sources exhibited strong language in explaining the economic development in the Quatre-Montagne forest. Because the main study of these sources is multifunctional forest management, the economic development in the forest includes different functions with different background (social and ecological); this exhibit great heterogeneity in the overall economic development. |
| S5 - market | Tissot and Yann 2013 (Report), AGRESTE 2014, FORGECO 2014 (French national project), ARANGE 2015 (European project) | These studies refer to the strong demand on the forest. This demand is exemplified in social and ecological functions (tourism, wood production, and nature conservation). In particular, the references clearly presented the importance of the different functions with a focus on their development due to the strong demand they face. The Quatre-Montagne forest belongs to the one of the most exploited ecosystem in the Europe (critical source of wood and a very important touristic destination). |