Which infrastructure for which forest function? Analyzing the multifunctionality through the social-ecological system framework

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Abstract

Landscapes are subjected to ecological and socio-economic forces of change, interacting in complex ways. To cope with these changes, landscape planning of natural resource management consists of integrating socio-cultural, ecological, and economic considerations in an analytic and systemic way. In this vein, social-ecological systems (SES) frameworks have been developed to help in analyzing key factors that derive the dynamics of such complex adaptive systems. For forests, multi-functional management, which also highlights the ecological and the socio-economic roles of forests for society, has become a central objective for several European countries (e.g. France, Italy, Germany). However, tools and conceptual approaches related to SES frameworks that enable us to understand the mechanisms behind such management approaches are still lacking. This study adopts Ostrom's SES framework and Anderies robustness framework to highlight how forestry institutions affect forest ecosystem, forest functions, and social arrangements. As an illustration, we apply our analysis to the Quatre-Montagne forest, located in the South-East of France, where multifunctional forest management is a major objective. We first consider the SES framework to construct a diagnosis of the Quatre-Montagne forest specifying the first-tier and second-tier variables. From this analysis, we highlight the importance of physical/social infrastructures in shaping the interactions between components of the SES. We outline that the robustness framework, developed by Anderies, serves to better explain management options of an ecologically-based SES. We discuss implications, based on our infrastructure analysis, which can be used when establishing management design for efficient forest management.

Key Words: Forestry; forest accessibility; robustness theory; social-ecological systems; infrastructures; recreation

1. Introduction

Forests provide a large number of provisioning, regulating, supporting and cultural ecosystem services that stabilize climate, protect plants and animal species, provide food and shelter to local communities, protect critical human infrastructure such as settlements, roads, and railway lines from gravitational natural hazards, and isolate large amount of carbon as a result of recycling of gases [Robert et al. 2002]. The ideal concept of maintaining a continuous flow of goods and services from the forest has occupied a central place in forestry thinking [Ciancio and Nocentini 1997, Puettmann et al. 2009]. Meanwhile, there is a raising awareness that managed ecosystems are characterized by complex dynamics with high uncertainty related to rapid environmental and socio-economic changes [Benson and Craig, 2014]. Analyzing interactions between ecological and socio-economic components of forest ecosystems and the consequences on their integrity calls for a multidisciplinary framework that provides a common language to understand emergent pattern of interactions. Ostrom's SES framework [Ostrom 2009] is useful for such analysis as it has been designed to be applied to different SESs that could range from lakes [Brook and Carpenter 2007] and irrigation systems [Cox 2014] to fisheries [Schlüter 2014] and forests [Nagendra 2007]. Forestry is now facing a challenge which consists in achieving sustainability in a changing environment with a better integration of interaction between ecological and social systems [Von Detten 2011].

Forest multifunctional management, which also highlights the ecological and the economic roles of forest ecosystems for society, has become a central objective for several European countries (e.g. France, Italy, and Germany) [Slee 2012]. Nocentini et al. [2017] argues that multifunctional forest management has been first based on the "wake theory" which states that if forests are efficiently managed for wood production, then all other forest utilities will follow [Kennedy and Koch 2004]. Dynamics and interactions from other systems tended to be ignored and the consequences have often been, and still are, conflicts (e.g. between timber production, landscape and nature conservation, and recreation) [Mckercher 1992, Steinhäußer et al. 2015]. Additionally, recent examples show that societal preferences and values can change remarkably in a relatively short period thoroughly changing the social environment for forest management [Johnson and Swanson 2009, Seidl and Lexer 2013]. When considering forests as adaptive complex systems [Messier et al. 2015] with multiple economic and social components, the concepts of multi-functionality change from a set of different outputs to a set of complex interactions [Nocentini et al. 2017]. In this context, multifunctionality can be embedded in the SES framework with in multiple tier variables which constitute an institutional analysis of the system.

The notion of social-ecological systems frequently used to frame common pool resources (CPR) problems, such as forests, does not always adequately captures important aspects of hard-human infrastructures (e.g. institutions, roads, canals, etc.) that conditions the interactions between social and ecological components in all SESs [Muneepeerakul and Anderies 2017]. Here, infrastructures are broadly defined to include natural and human-made infrastructures (both physical and social) that enable the operation of society. The commonly used term "social ecological systems" typically emphasizes the interaction between a set of infrastructures related to social and ecological processes.

SESs such as forests often exhibit non-linear dynamics as the rules of local interaction changes over time [Levin 1998]. Humans act alone on components of the system attempting to adapt, to change, or to transform the system when existing interactions can no longer be supported by its components [Walker et al. 2004]. A SES is considered robust if, when exposed to disturbances, institutions and human interactions are able to prevent shifts that would make people unable to harvest the resource [Anderies et al. 2004]. In this context, Anderies's [2004] robustness framework, based on Ostrom's SES framework, can be used to provide a systematic way of thinking that focuses on how infrastructures interact in terms of the functions they provide.

In this article, we investigate how multifunctional forest management can be framed and analyzed through understanding the functionality of the forest SES. In particular we outline how different components of the SES interact to produce diverse functions of the forest. To do so, we provide an application of Ostrom's SES [Ostrom 2009] framework to a mountain forest case study area (Quatre-Montagne forest) where forest multifunctionality is a major management objective. As infrastructures (composed of buildings, roads, institutions, rules, etc.) play an important role in how different parts of the system interact (e.g. exploitation of the forest by actors), we show that the robustness framework, based on Ostrom's SES framework, is a suitable tool to provide a new perspective of the focal SES based on infrastructures. We then present multiple functions of the forest through the lens of the robustness framework by applying it to each forest function.

Our main contribution lies in the representation of the multifunctional management through an infrastructural point of view. We use the two frameworks mentioned (SES and robustness frameworks) as a tool to explain the institutional arrangement behind multifunctional management practice. The proposed framework allows us to highlight interactions and conflicts between forest functions, but also, help in addressing them through identifying infrastructures that underpin these interactions. The proposed view of the framework provides a more integrated view of the forest functions by connecting them through social and physical infrastructure. Our ultimate goal is to help resource managers address three key issues: to characterize the dynamics of the resource, to describe the governance revolving around forest management, and to specify the associated infrastructure that contributes to the successful management of the resource.

2. Case study

The data used to build up the analysis is taken from a national funded project (called FORGECO project [2014]). The data describes several aspect of the case study (including location, economics, ecology, social structures, etc...). This 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. 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, (v) resilience and scenario viability analysis, (vi) participative approach structured by the method of game territory [Lardon et al. 2016].

Forests in the European Alps provide a wide variety of ecosystem services (ES) for owners and society by creating income through timber production, protecting infrastructure from gravitational natural hazards, providing high quality drinking water and mitigating climate change through the uptake and storage carbon [Price 2003, Nabuurs et al. 2014]. Moreover, mountain forests are important aesthetical assets for tourism [Nepal and Chipeniuk 2005]. Despite intensive use of timber, the Alps forest has maintained its relatively natural state and is a hotspot for biodiversity and tourism [Nagy et al. 2003].

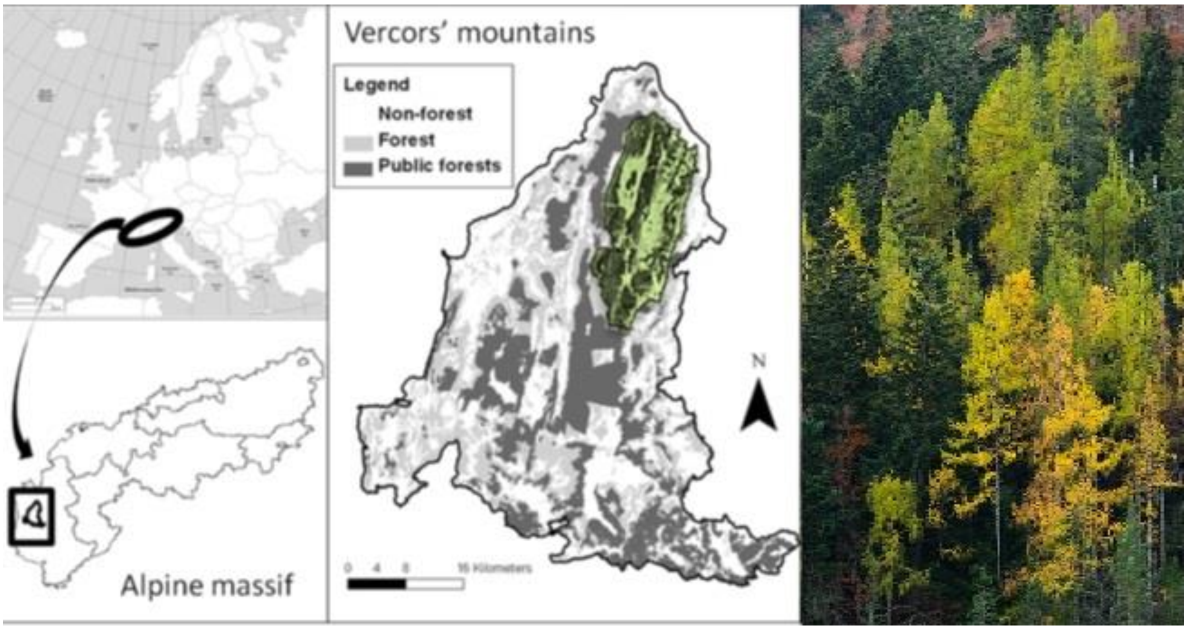

Figure 1. Study area location in the Alpine Mountain Range and the site of 'Quatre Montagnes' at the north of Vercors Regional Park (VRNP), FrenchAlps.

The Vercors regional natural park (VRNP) is a 206,000 ha area located at the border between the Northern and Southern French Alps (Fig. 1). 139,000 hectares of VRNP are dominated by forest land, with altitudes varying from 180 m to 2453 m. The main tree species are Silver Fir, European Beech, and Norway Spruce especially present in the Quatre-Montagne area. A mosaic of stands types with different tree sizes and varying species richness are now present. At low elevations (500 – 1100m), the forests are dominated by old simple coppices or mixed coppice and high forest and are generally composed of broadleaved species and silver fir standards. These forests have been mostly shaped by the heterogeneous mountain topography and a long history of human intervention. During the 19th century, almost all the forests were intensively exploited for firewood, which favored beech coppices. Since the early 20th century, they have been progressively converted into mixed high forests, sometimes through conifer plantation but often by natural regeneration of local coniferous species. Approximately half of these forests are public (State and Municipality forests – dark grey in the map) [Gonzales-redin et al. 2015] and the rest is in the hands of private stakeholders (light grey). The particular case study selected for this research focuses on 25,000 ha (12% of the total area) located at the North of Vercors regional natural park, in an area known as 'Quatre-Montagnes'. Fig. 1 shows the Quatre-Montagnes region within the Regional Natural Park in the French Alps, (in dark green, public forests). The area is a part of the Grenoble agglomeration with implications for impacts of tourism.

In accordance with the principles of preserving biodiversity and reducing gas emission (adapted from the earth summit in Rio de Janeiro 1992), the law on the forest orientation [2001] recognized multi-functionality of the forest. Alpine countries support the contribution of the forest to sustainable development of their territory. The general environment forum and the council of forests led to the adoption of a protocol of understanding among forest managers: to produce more wood while still preserving the biodiversity by favoring a territorial approach concerted in the framework of multi-functional forest management. In the Vercors, nature conservation plays an important role and even though multi-functionality is considered as essential with wood production, recreation and biodiversity being consolidated at all scales (Kurttila 2001; Öhman & Lämas 2003; Baskent & Keles 2005). However the topography infers an obstacle as 36% of the forest is actually non accessible and not exploitable for timber users [Fiche de territoire 10].

The governance of the resource in the Vercors area is composed of three levels; region (also presented by the PNR), department, and communes. The region develops its own strategies and support territorial projects (for example the regional strategy for economic development and innovation (SRDEI) and sustainable development contracts with territory projects (CDDRA) with the objective of mobilizing wood in the area and limiting the gas emission. The departments aim to reinforce rural/urban environment multi-functionality by developing its own strategies and supporting the territorial projects (for example, developing agriculture strategic plan). The communes, considered as owners, develop and promote wood production in the area and in addition lay grounds for the territory forest charters (*Chartes Forestiers de Territoire*, CFT in French) and execute operational expression of the different guidance documents that impacts the territory. Specifically, the Territorial Forestry Charts represents a new flexible structure of local governance specific to France, introduced by the *Law on the Forests 2001* as an instrument of sustainable development or rural territories through inclusion of the advantages brought by forests into their economic, social and cultural environment and multi-functionality of forests [MAP 2001]. Being based on stakeholders participation, CFT is entirely in line with governance – the National Forest Program (NFP), as defined by the MCPFE (The Ministerial Conference on the Protection of Forests in Europe) [MCPFE 2002], with participatory mechanisms, decentralization, and empowerment of regional and local government, an increased role of local communities and secure land-tenure arrangement [Kouplevatskaya and Buttoud 2009]. Following the European priorities, the CFT institutionalization aim is to integrate the forest as a core territorial policy together with other major issues such as development of tourism, water management, etc.

3. SES framework diagnosis

The SES framework [Ostrom 2009] identifies the broad characteristics of Resource System and related Resource Units, Governance Systems, and Actors that together affect the structure of Action Situations leading to Interactions and Outcomes, as well as being embedded in Social, Economic, and Political Settings, and with Related Ecosystems (see figure 2). Within each of these broad structures there are second-tier variables, and frequently, third-, fourth- and fifth-tier variables. This nested hierarchy of variables was not proposed with the intent to suggest that all the variables are relevant for all the cases. Rather analysts might find the SES framework helpful as a diagnostic tool that enables them to define clearly variables of interest and organize them into connected groups.

3.1 Resource and resource unit subsystem

The Quatre-Montagne SES (figure 2) can be characterized by the forest as a RS. The forest cover is about 17000 ha and is labeled as public (communes) (60%) and private (40%). The area contains a lot of human-constructed facilities related to tourism (accommodation, restaurants, sports and leisure, etc...), timber industry (sawmills, side road wood deposition place, etc...), or both (i.e. roads) [Achard 2011]. Changing socio-economic factors have led to a suite of land-use changes in the forested areas, and significant changes in the provision of some ecosystem services [Parmentier 2013]. For example, using the forest (trees) as an obstacle against rock fall, conservation of the ecosystem (a forest reserve is present all around the study area), developing tourism (ex. ski resorts, green tourism), timber harvest, and many other functions.

Keeping in mind that the forest is very generative in terms of wood production, tourism is also considered a major industry in the area; this is due to the mountainous terrain which makes it an all-season touristic area [Fiche territoire 12]. Nevertheless, within the Vercors regional park, the forest participates in the image of “nature preservation” or “landscape esthetic” [Tenerelli et al. 2016] which, side by side with winter tourism, is the main engine for the local tourism. However, the area is widely exploited in terms of timber and in both public and private forests. Thus conflicts exist between different actors of timber and tourism industry, the objective of the current forest management entails “produce more while protecting better” strategy [Achard 2011]. Within the forest, there are diverse species of trees (RU) such as Silver Fir, Norway Spruce and European Beech, which makes its economic value high, but due to the mountainous terrain, timber industry faces particular difficulties linked to the mobilizing of the resource [Avocat et al. 2011]. Therefore, some parts of Quatre-

Montagne forest are under-exploited [Puech 2009] which leads to the aging of these stands, and therefore, degradation of wood production function.

3.2 Actors and Governance system

3.2.1 Private forests

Since 1963, forest owners have been required by law to create statutory document called "Plan Simple de Gestion" (PSG) to be validated by the regional centers of forestry property (CRPFs). This document is described in the forestry code and integrated into the sustainable management policy of French forests [Tissot and kahler 2013]. PSGs must be in compliance with the regional woodland management schemes (SRGSs) set up by the CRPFs to define woodland management practices adapted to each region. Owners of small forests can either subscribe to a code of good forestry practices (CBPS) which makes forestry practices easier and permits them to receive subsidies from the state, or file a management regulation in which it describes forestry

3.2.2 Local or regional forests

The french forestry regime implemented by the ONF ensures the sustainable management of forest resources belonging to local and regional authorities. It is perfectly able to cope with multiplicity of public owners and the need to combine the long-term rhythm of the forest short cycles of elected office. At the national level, annual timber harvesting is less than the annual forest growth, and thus, an increase of timber harvesting has been decided through the State-ONF-FNCOFOR[1] contract with the view of stabilizing the wood capital [Tissot and Kahler 2013]. The income derived from timber harvesting is vital for rural communes. Activities around logging generate jobs that contribute to the maintenance of population in rural areas. In addition to creating associations for promoting best forest uses, public forests provide open and accessible spaces for leisure activities. Local authorities invest in tourist infrastructure in the forest in order to guarantee a good living environment for the population [Aggestam and Wolfslehner 2013]. Fully aware of the multi-functionality of the forest, communes have joined the CFT with the aim of not only as a flexible tool, but also as a proposition of a conceptual framework to the local stakeholders for the integrated development of forests with a participatory definition of precise objectives and local actions [Kouplevatskaya and Buttoud 2009].

[1]National Federation of Forest-Owning Communes

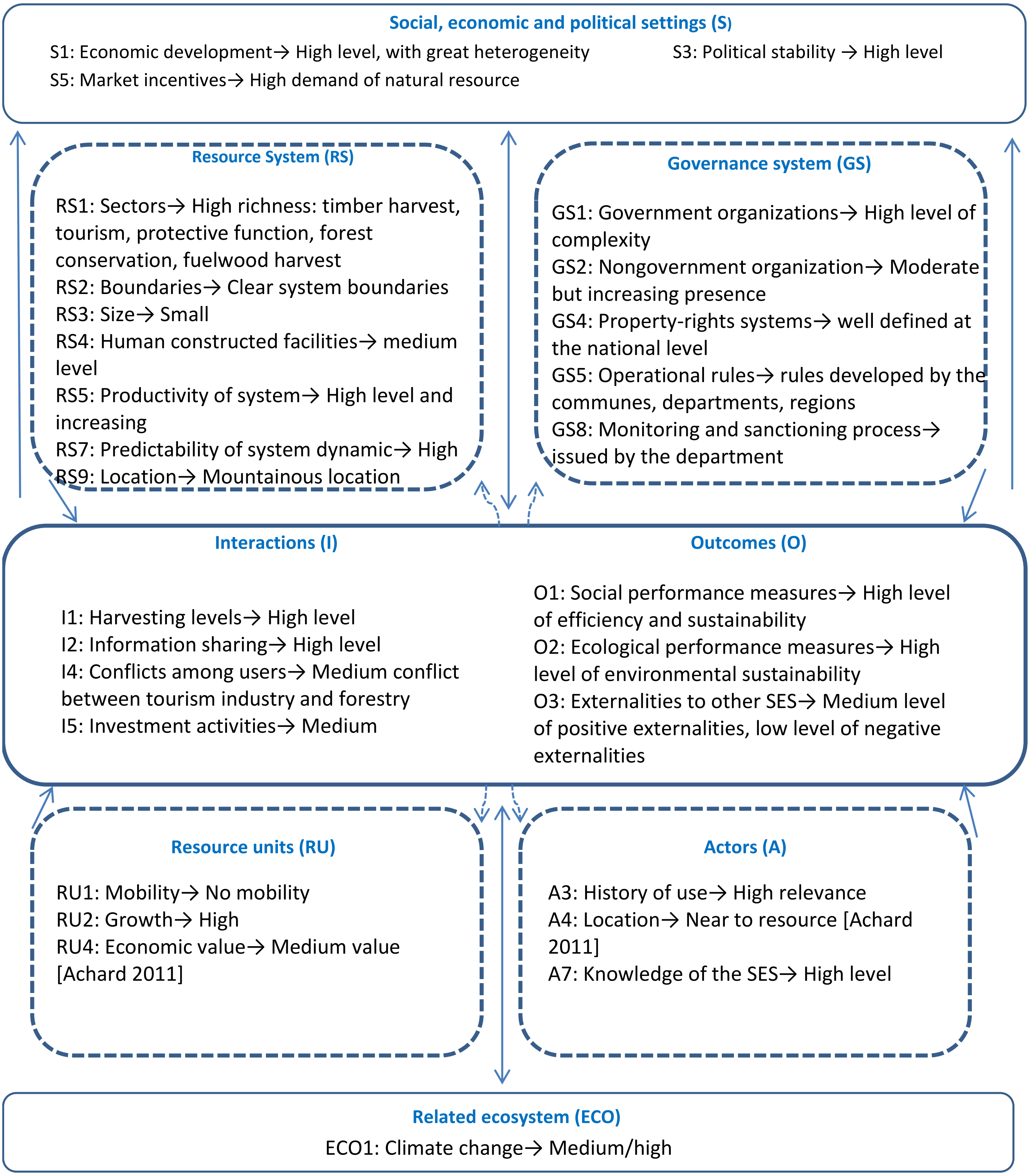

Figure 2. The modified SES framework for the Quatre-Montagne case study. solid boxes denote first-tier categories. Resource Systems, Resource Units, Governance Systems, and Actors are the highest-tier variables that contain multiple variables at the second tier as well as lower tiers. Action Situations are where all the action takes place as inputs are transformed by the actions of multiple actors into outcomes. Dashed arrows denote feedback from action situations to each of the top-tier categories. Exogenous influences from related ecological systems or social-economic-political settings can affect any component of the SES.

3.2.3 Governance

The bulk of the funding of the governance functions comes from the subsidies that are offered by the European Union (EU) for the purpose of supporting multi-functional sustainable forest management [Sarvasova et al. 2014]. The state, as a central decision making apparatus, has through a mutual adaptation of priorities and positions given the leading role in the CFT to the communes represented at the national level by the FNCOFOR. Thus, according to France's decentralized forestry regime, the governance functions are shared by three different organizations (Municipals, Region, and Departments). First, municipals are considered as owners of public forest and they act on the forest through the ONF to elaborate management plans and to exploit the communal areas following regional and national recommendations for biodiversity and environmental preservation. In addition to setting up the "rules-in-use" of public infrastructures (i.e. road and tracks usage), municipals invest (subsidies from the EU) in infrastructure for the enhancement of the user-resource interaction. Second, the region is responsible, through the PNR (regional natural park) and the DRAAF (Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt) [see the official websites for the PNR and the DRAAF for functions], for implementing policies that helps developing the forest sector as well as maintaining the biodiversity of the environment. Moreover, objectives of the regional organizations consist of mobilizing timber for exploitation, and deploy snow canons as artificial technique to assist winter tourism. Third, the department is responsible for sanctioning and monitoring, and establishing sensible areas to protect biodiversity, and additionally, departments receive subsidies by the EU to construct roads to enhance accessibility to the forest and facilitate timber mobilizing in the area. On one hand, all forests belonging to municipals or public institutions are considered to be public utility and therefore managed according to the French forestry regime (a direct effect on the forest management). Thus forests are liable to strict management planning. This management has to integrate the multi functionality of the forest and not just production. On the other hand, private forest owners of more than 25 ha are required by law to create a statutory document called the "Plan Simple de Gestion" (PSG), to be validated by the regional centers for forestry property (CRPFs). This document is described in the forestry code and integrated into the sustainable management policy of French forests. The regional strategic documents of sustainable forest management are all approved by the state, for public forests as well as for private forests. The composition of these regional commissions reflects the diversity of the actors involved in forestry at regional level [Tissot and Kahler 2013].

3.3 Key elements and conclusions of the SES analysis

3.3.1 Tourism and nature conservation

Forests are very important part of the landscape especially in the Vercors area. Many outdoor recreational activities can be undertaken in a forested area. These could be among the reasons why the studied perception emphasize that the role of forests in tourist and recreational activities was vital in the study area [Bori-Sanz et al. 2002]. The more forests in the region, the more important were they perceived for recreation and tourism. Though, the mere existence of forests in the area may not be enough to promote tourism, but other activities, services and infrastructure are also required. As Hyttinen et al. [2000] pointed out, abundance of forest resource, as such, do not create employment. Other structures and services are also needed. Moreover, nature conservation is an important function of the forest contributing to the increase of the forested area, enhancing of the ecology of the forest, and sustainability of the resource. Although these two goals frequently enhance each other, sometimes pursuing both simultaneously can result in conflicts. In some cases, recreational use can so severely degrade an area that not only is the environment damaged but the quality of the recreational experience itself is diminished [Cole 1993]. On the other hand, the closure of the landscape can be detrimental to scenic beauty and thus recreational activity [Tenerelli 2017]

The analysis indicates that in the sites where tourism has been promoted, for instance, through the establishment of protected areas, there are apparent economic benefits for the local population. Stynes [1997] reported the positive economic impacts of tourism. Nevertheless, tourist activity in natural areas needs to be managed carefully, as well as planned and organized in advance, in order to maximize the benefits for locals and enhance nature conservation at the same time.

3.3.2 Forestry

As shown before, the Quatre-Montagne forest varies greatly in terms of species, productivity, major roles, and ownership. Forest cover is increasing in the area [European Observatory of Mountain forests, 2000]. Furthermore, the forest play significant role in the economy of the area through providing employment, maintenance, harvesting, wood processing, fuelwood; as well as contributing to opportunities for recreation and tourism; providing habitat for fauna and flora; and contributing to the value of the landscape. Moreover, timber wood production, and fuelwood production is considered the most important aspect the Quatre-Montagne forest [Aggestam and Wolfshlehner 2013].

Nevertheless, in order to meet the demand on the forest, exploitation of the forest resource has to increase [Tissot and Kahler. 2003]. Some behavioral reluctances are added to technical and economic difficulties; the topography infers another obstacle, which has some effect on the price of the timber. The number of forest holders using skidders has decreased, whereas 62% of Rhone-Alps forest area is considered as “difficult to exploit” [Avocat et al. 2011].

3.3.3 Road infrastructure

The FFN (National Forestry Fund) had a strong impact on the environment and the economy in the area. It led to a quick increase in the forest area and allowed for the creation of infrastructure (i.e. roads and tracks) which made logging easier and more efficient [Tissot and Kahler 2013]. Nevertheless, as a mountain forest, infrastructures provision (forest roads) in the Quatre-Montagne area is generally perceived as being scarcer and of poorer quality than in other parts of Europe due to its topology. For example, FORGECO [2014] shows that 35.99% of forested area in the Quatre-Montagnes is actually non-accessible, and therefore, non-exploitable. Therefore, the area is lagging behind and faces difficulties related to lack of accessibility, which restricts both forest industries and recreation [Mountain areas in Europe – Final report]. Reduced accessibility, for forestry and tourism function, is consequently the most unanimously recognized drawback of Quatre-Montagne forest compared to other forested areas across Europe.

3.4 Conclusions

The development of wood exploitation in the Quatre-Montagnes area refers to the way resources may be appropriated in a highly heterogeneous area. The economical and logistic construction of the wood chain has to deal with a constraining geographic frame, including the difficulties to access the resource (linked to the poor condition of infrastructures in mountain areas), the multi-functionality of the mountain forests, and the fragility of the ecosystem [Mina et al. 2017]. Moreover, beyond the mobilization of technical disposals to improve the qualifications of the resource, and to enhance economic, energetic or environmental efficiency along forestry and recreational activities, identifying and understanding the structure and its dynamics are conditions for the forest resource sustainability and thus for the sustainability of the services it provides (i.e. tourism), and finally for a sustainable territorial development.

Moreover, the diverse animation process launched by the timber actors on one hand and by the tourism actors on the other hand, have made clear the need for a common language between the different worlds committed. Such a common language will have to be built at different institutional levels, between actors having to confront their strategies at their specific scales.

Next, we apply the robustness framework in our analysis of this data to understand how key features of multi-functional SESs interact with each other.

4. Forest Multi-functionality through the lens of the robustness framework

4.1 Introduction

The importance of applying the SES framework lies in the analytical description of the case study in hand that embraces institutional[2] complexity by going through multiple tiers of variables. Nevertheless, Muneepeerakul and Anderies [2017] suggests that the notion of social-ecological systems frequently used to frame common pool resources (CPR) problems does not adequately captures important aspects of hard human-made infrastructures that conditions the interaction between social and ecological components in all SES's. Furthermore, the authors specifically seek to address problems associated with the fact that the importance of infrastructure is often invisible to users until it fails. The commonly used term "social ecological systems" typically emphasizes the interaction between a set of infrastructure related to social and ecological processes.

We use the robustness framework [Anderies et al. 2004] (figure 3) to analyze the dynamics of the forest SES. The framework delineates four components of the SES (resource, resource users, public infrastructures, and public infrastructure providers), their interactions, and how these components and interactions influence the capacity of a SES to cope with internal and external disturbances. This framework explicitly recognizes the role of public infrastructures in influencing the system on the component level. Public infrastructure can be either "hard" (e.g. roads and buildings), or "soft" (e.g. formal and informal institutions, rules, social structures) and is typically designed to achieve certain societal output [Muneepeerakul and Anderies 2017].

[2] *In the context of the Ostrom's framework, institutions are understood as formal and informal rules that shape human interactions [North 1991]*

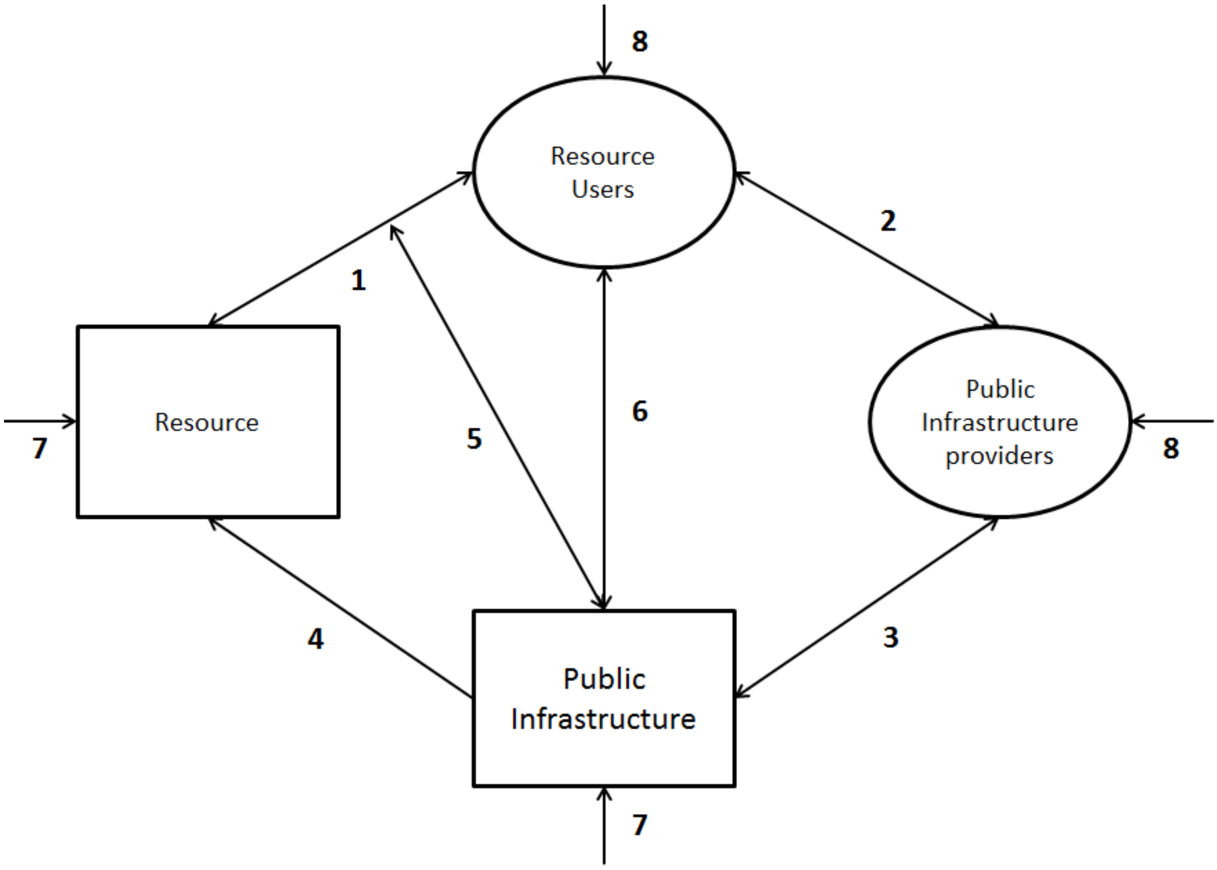

Figure 3. The conceptual model of the robustness framework as introduced by Anderies et al. [2004]. it specifies four generic components common to most social-ecological systems (resource, resource users, public infrastructure, and public infrastructure providers) and their interactions (Links 1 to 6). It also describes the presence of external disturbances (Links 7 and 8). Boxes reffer to biophysical components of the system while circles reffer to social components.

The robustness framework can be used to 1) provide a systematic way of thinking that focuses on how these different infrastructures interact in terms of the functions they provide that avoids artificial and potentially misleading distinctions between various systems, and 2) recognize and clarify the "configural" nature of the system, i.e. minimal set of infrastructure classes is required before interesting higher-level organizational patterns emerge (i.e. well-being, communities, societies, etc.). When thinking in terms of robustness framework the question is not "what is the right policy or set of institutions for a particular problem or context?" but, rather, "what infrastructure can we influence that might nudge the system to evolve toward a robust configuration that produces mass and information flows valued by the society?" [Anderies et al. 2016]. In what follows, we provide a general analysis, adopted from the SES framework analysis, of the case study through the robustness framework perspective. In particular, we use the robustness framework to provide an infrastructural point of view of some of the forest functions, and in the process, emphasize the importance infrastructures in contributing to the operation and development of each of the functions mentioned (Table 1).

4.2 *Timber and biomass for energy functions*

The forestry sector is an important wood provider for basic human needs and an important employer and has the potential to create even more jobs in the future. Moreover, according to the *Comité du massif des Alpes* set up by the French national planning agency, sustainable planning of the forest harvesting will have become an important issue by the year 2020, and the energetic valorization will be a part of the alpine forest strategy [Avocat et al. 2011]. Several planning tools (e.g. *Schéma stratégique forestier du massif des Alpes* and the *Inter-regional Convention for the Alpine Massif*) clearly aim at a rise of wood (e.g. fuelwood) utilization in the Vercors, provided that it meets mountain specificities and their vulnerabilities. Thus, the development of the forestry sector is obviously based on an increase in wood demand [AGRESTE 2014]. Table (1) shows the timber and biomass for energy function of the forest through the point of view of the robustness framework. Forest owners use physical and social infrastructure to help in wood production from the forest, and in the process, the forest owners acquire characteristic information about the forest (Link ①). Resource users (RU) provide money to the public infrastructure providers (PIP) in the form of taxes which allows for its operation, and in addition resource users elect the public infrastructure providers (Link ②). PIPs produce public infrastructure (PI), both physical and social, such as roads and forestry institutions, and in return information flows back (Link ③). PIP through building PI aims, not just to offer a tool for enhancing wood extraction, but also to enforce rules through which it can prevent overexploitation and degradation of the forest. Information about forest owner's activity flows back to the PI (Link ⑤). Enables or restricts actions of RUs by providing knowledge that changes RUs perception. For example, the change to multi-functional forest management by a better perception of knowledge (Link ⑥).

4.3 *Tourism function*

As shown before, tourism industry, and the presence of large numbers of tourists, has played an important role in mountain transformations in recent decades in many European countries, particularly in the Vercors, where tourism in some locations dates back to the mid-19th century. Table (1) shows the tourism function through the point of view of the robustness framework. Tourists take advantage of physical and social infrastructure to produce cultural services from the forest and conversely publicity and information about the resource flows back to the users (Link ①). Tourists and tourism companies contribute to the governance (PIP) in the form of TVA taxes, permits, license fees and elections (Link ②).

The governance use resources from tourists to construct public infrastructures (rangers, restaurants, etc.) that are essential for the flourishment of tourism in the forest (Link ③). Infrastructures contribute to the publicity of the touristic area as well as the publicity (Link ⑤). In addition, infrastructures provide knowledge for and enforce laws on tourists (Link ⑥). In return, infrastructures collect information on the tourists and the tourists' activity in the forest that can impose laws to adapt management for recreational activities

4.4 *Nature conservation function*

The Vercors forest belongs to one of the most preserved ecosystem in Europe, and as such it is subject to nature conservation [Sarvašová et al. 2014]. Despite successful implementation of multi-functional forest management in the Vercors, conflicts between nature conservation and other sectorial policies regarding management of mountain forests were reported from some regions. Table (1) presents the nature conservation function through the perspective of the robustness framework. Conservationist and forest managers (e.g. ONF) help in conserving the forest through the utilization of infrastructures (associations, environmental organizations, and scientific studies), and information is gathered on the ecology of the forest (Link ①). Forest users provide resource (taxes) to the governance and participate in electing it (Link ②). In return the governance produce infrastructures such as PNR, nature conservation, and environmental laws that can help in the forest conservation process (Link③). Furthermore, institutions enforce laws that benefit the preservation of nature and thus enhance the effort exerted by conservationists on the forest (Link ⑤). Additionally, institutions contribute to an increase in the nature conservation activities by providing knowledge to users, and spreading out awareness (i.e. PNR) (Link ⑥).

		Functions			
	Forest	Timber production/ biomass for energy production	Tourism	Protection	Nature conservation
Robustness framework	User activity	+++	++	+	++
	Users	Forest owners	Tourists, ski companies	Tourist, Foresters	Conservationist
	PIP	Municipals, departments, regions			
	PI	Roads, sawmills, ONF, DDT, CCMV, etc.	Roads, PNR, CCMV, restaurants, ski centres, etc.	ONF	PNR, DDT, CCMV, Protected areas, etc.
	Link 1 (U↔Forest)	Timber exploitation	Cultural services	Infrastructure protection	Conservation of natural infrastructure
	Link 2 (U↔PIP)	Permit taxes	TVA and license fees	none	Elections
	Link 3 (PIP↔PI)	Provisioning of forest roads and forestry institutions	Provisioning of accessibility, rangers, accommodation, etc.	Provisioning of natural infrastructure	Provisioning of forest regulations and nature conservation institutions
	Link 4 (PI↔Forest)	none	none	none	none
	Link 5 (PI↔Link 1)	Regulations for preventing damages for the forest	Regulations for limiting the effect on the forest ecosystem	none	Enhancement or restriction of the effort for conservation
	Link 6 (PI↔U)	Guarantying sustainable forest management (regulating environmental impact and resource exploitation and issues taxes)	Constraining the access to the forest to avoid conflicts and limits negative environment impacts	none	Increasing nature conservation activities through regulating forest management practices and monitoring
	Link 7 (exogenous variables affecting natural and human-made infrastructure)	Climate change (affects tree growth, survival and regeneration)	Climate change (affects ski tourism and related activities)	Climate change (more fires or insects inducing secondary natural hazards)	Climate change (affects the biodiversity and forest ecosystems)
	Link 8 (exogenous variables affecting social infrastrucutre)	Market variability	Political stability	none	Social incentive and political stability
Infrastructures	Soft-human made	+ (DDT, ONF, CCMV, etc.)	++ (PNR, CCMV, etc.)	+ (ONF)	+++ (PNR, DDT, CCMV, etc.)
	Hard-human made	+++ (Raods, sawmills, etc.)	++ (Restaurants, ski centers, roads, etc.)	+ (None)	+ (None)
	human	++ (Forest owners)	+++ (Tourists and business men)	+ (Tourists and foresters)	+ (Conservationist, tourists, foresters)
	Social	+ (web of relations between forest owners)	+++ (Publicity and web relations)	+ (information sharing with the ONF)	++ (Awareness and web relations)
	Natural (forest)	+++ (Trees)	+++ (Natural environment)	+++ (Trees)	+++ (Natural environment)

Table 1. Forest functions from the point of view of the robustness framework and infrastructures

4.5 *Protective function*

Mountain forests in the Vercors have an important protection function against natural hazards such as rock fall, snow avalanches, shallow landslides, and erosion [Aggestam and Wolfslehner 2013]. The primary function of the protection forest is to protect people or assets from the impacts of natural hazards. The key product of the forest is the standing trees that act as an obstacle to the acquisition of the initial conditions necessary to the release of mass movement hazards or downslope propagation of these hazards. Table (1) expresses the protective function of the forest from the robustness framework perspective. Users (i.e. forest owners, public, and private institutions, etc.) use strategies to concentrate the forest with the purpose of protecting infrastructures (Link ①), in return, users elect the governance (Link ②) which, in terms, provide infrastructures that are essential for the operation of this function (Link ③). All of these interactions occur while information eventually flows back to the resource.

4.6 *Exogenous variables*

Although the forest is a system that is governed by social and ecological subsystem, it is also affected by exogenous variables (affecting, both, social and physical aspect of the forest) that are affecting the forest at the global scale. Economic instability affecting timber and fuelwood markets and, therefore, introducing high variability and uncertainty to the stock market. Nevertheless, global climate change also has an effect on the ecology of the forest and, consequently, on the functions of the forest. Snow scarcity and an effect on the tree regeneration, growth, and survival have been observed on the forest scale. In the Quatre-Montagne, Negative impacts of climate change were evident for the provision of ecosystem services. Synergies and trade-offs between the majority of ecosystem services were found to be sensitive to the choice of management and climate change [Mina et al. 2017].

5. Analysis and discussion

From the analysis done previously we can conclude that there are four functions that are widely practiced in the Quatre-Montagne forest (timber production, fuelwood production, tourism, and nature conservation) [see also ARANGE 2012]. Figure (4) represents a modified conceptual map for the robustness framework that takes into account the four important functions in the Quatre-Montagne forest. The current paper focused on defining what set of infrastructures (or institutions) contribute to a sustainable multi-functional forest management. The proposed method can demonstrates how qualitative analysis can be used to formulate an understanding of the socio-ecological system to help in designing governance and management strategies for forests. Infrastructures are critical component of the progress of forest functions in the area. Nonetheless, developing and maintaining the industrial activity that is vital for the societal flourish would be difficult without infrastructures. Decisions about infrastructures alignment, building maintenance, or decommissioning are complex because of the many tradeoffs involved [Lugo and Gucinski 2000]. For instance, the tradeoff between access to roads for recreation and forestry with the potential of that access on biodiversity and nature conservation [Caliskan 2013]. Multi-functional forest management can be difficult to achieve without a proper infrastructure framework and mechanism. The application of the robustness framework has provided us with a qualitative linking between the forest functions and institutions. Knowledge of how institutions change the forest functions capacity is key, and in turn, this knowledge permits us to understand the scope for purposive design, the main obstacles to instrumentality, and the strategies followed when approaching change.

5.1 A function or an infrastructure?

From the robustness framework analysis, the structure of the system components is primarily defined by institutions. The analysis identified a correlation between how the multi-functional forest management work and institutions, thus offering a control on the development of forest functions. For example, timber function depends on the availability of "accessibility infrastructures" such as roads, or tourism function requires the availability of both physical and social institutions. Thus a suitable design of infrastructures can contribute to a better application of the multifunctional forest management by putting an emphasis on forest functions more than others.

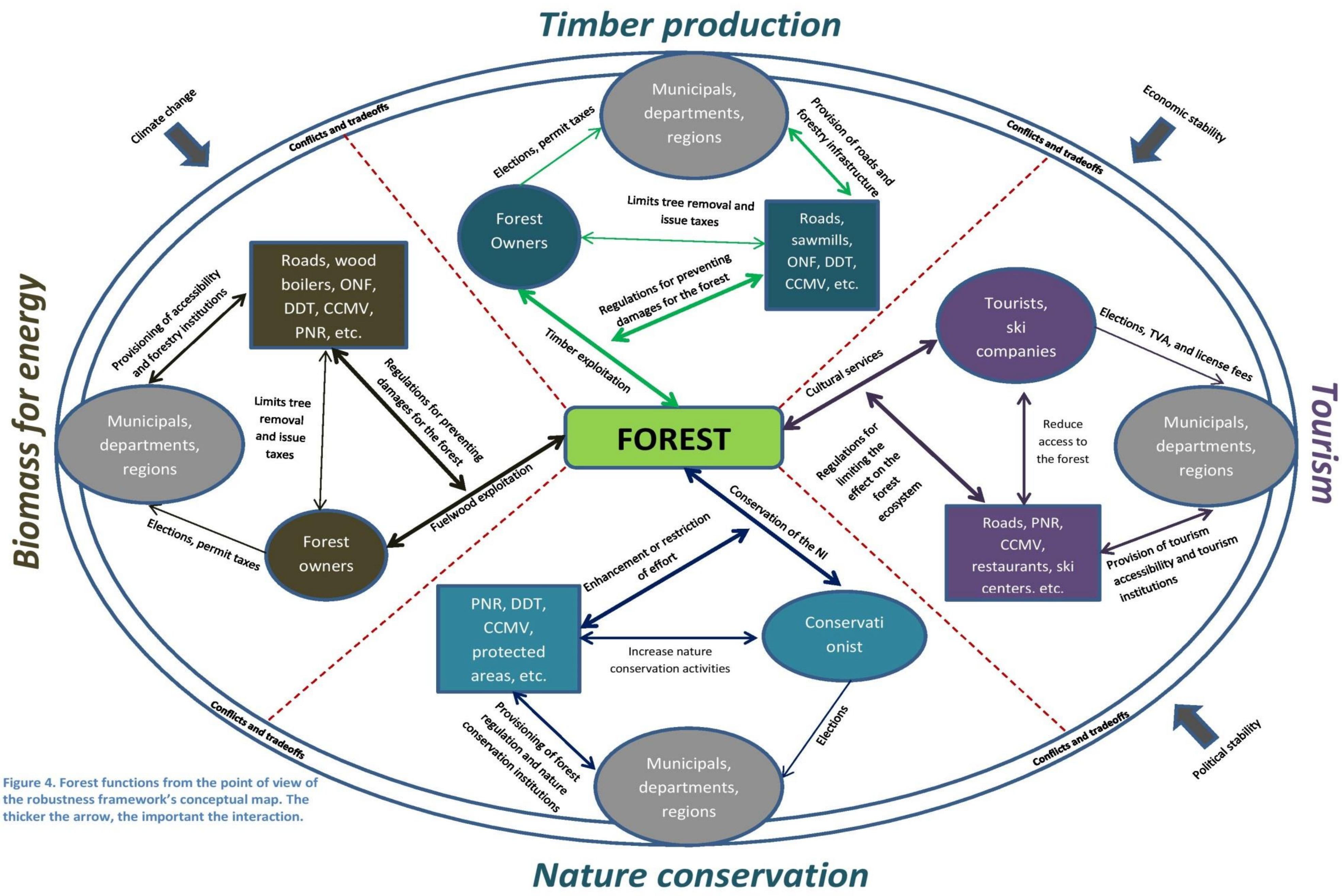

Figure 4. Forest functions from the point of view of the robustness framework's conceptual map. The thicker the arrow, the important the interaction.

5.2 Implication for designing forest management policies in the Quatre-Montagnes

Well planned design and robust approaches to the conceptualization of forest socio-biophysical interactions is a critical component of forest management [Prato and Paveglio 2014]. Its importance increases as forest provision demand becomes closely tied with societal incentives. Managing forests for different functions can be enhanced by investing in the associated infrastructures of each function. Recent work [Frischmann 2005, Rose 1986, Anderies et al. 2016] analyzes the ways in which the special nature of infrastructure affects both how it is provided and its impact on economic activities. Essential to this argument is thinking carefully about the many ways infrastructures generate difficult-to-observe effects that generate values to society. Thinking in terms of positive and negative effects has been used by Anderies in the coupled infrastructure systems representation [Anderies et al. 2016]. In fact, the authors argued that not considering these effects can distort institutional analysis by placing too much emphasis on the problem of providing infrastructure and allowances for suppliers to capture the benefits of infrastructures while neglecting the importance of demand for the many values infrastructures may provide. For example, concluding from table (1) and particular to the Quatre-Montagnes forest, table (2) shows that investing in hard-human made infrastructures for forestry functions (e.g. roads) offers more accessibility for tourists, thus a benefit for the function which demands more investments in other infrastructures for tourism function such as social infrastructures (e.g. publicity), Nevertheless, this investment may increase potential conflicts between multiple forest functions which then requires more social capital between stakeholders. This generic view of forest multifunctionality has provided us with a qualitative investment decision tool that synthesizes the different effect one investment can apply on other infrastructures related to the same forest function as well as other functions.

5.3 Conclusion

Robustness framework can help navigate the complex feedback and guide management practices. Forest system possesses great economic, ecological, and social values and can be maintained despite uncertain conditions. The robustness framework works well for analyzing the SES of the Quatre-Montagne mountain forest because of the importance of infrastructures in affecting the dynamics of the system. For example, lack of forest roads as infrastructure limits the forestry exploitation and in terms can increase susceptibility to disturbances and to climate change effect. The current challenges within the forest SES are the results of the governance failures in addressing the multifunctionality management of the forest. [Riggs et al. 2018, Johansson 2018]. For instance, Sarvašová et al. [2014] reported that despite successful implementation of multifunctional management in European forests, conflicts arose between different functions which indicated both deficiencies in intersectional cooperation and government failures.

Table 1. Effect of investment of hard-human made infrastructure for forestry function. Green signifies investment, blue first-tier effect, orange second-tier effect, and purple third-tier effect.

		Timber production/ biomass for energy production	Tourism	Nature conservation
Infrastructures	Soft-human made	+ (DDT, ONF, CCMV, etc.)	++ (PNR, CCMV, etc.)	+++ (PNR, DDT, CCMV, etc.)
	Hard-human made	+++ (Raods, sawmills, etc.)	++ (Restaurants, ski centers, roads, etc.)	+ (None)
	human	++ (Forest owners)	+++ (Tourists and business men)	+ (Conservationist, tourists, foresters)
	Social	+ (web of relations between forest owners)	+++ (Publicity and web relations)	++ (Awareness and web relations)

6. Overview and future directions

We applied the SES framework to examine the multiple social and ecological factors that potentially affect the biophysical outcomes of the forest in Quatre-Montagne area, France, and in the process we outlined the first and second tier variables that characterize the system. The analysis showed that there are a lot of ecosystem services that are offered by the forest such as timber harvest, tourism, fuelwood harvest protection function, and nature conservation. The economic construction of forestry has to deal with some constraints of inducing multi-functional management, fragility of the ecosystem, and more importantly, the geographic constraints that limit the accessibility to the forest. Therefore, the main aspect influencing the outcomes of forestry is the availability of infrastructure in the forest, and more importantly, infrastructure related to the accessibility of the forest. Moreover, following the conclusion by the SES framework diagnosis, we apply the robustness framework to our case study which offers an infrastructure perspective of the focal SES. We introduce each of the forest functions through the lens of the robustness framework emphasizing the important infrastructures that influence the operation of each forest function, and therefore, an investment tradeoff between the functions is observed.

The expanding of the human activities keeps the overall rates of the forest disturbances high. A new approach that controls forest exploitation while taking into account the needs of the local population is imperative. Construction of infrastructure is one of the points fostering effectiveness of multi-functional forest management. Thus, it is necessary that design, establishment and management of infrastructures be carried out with correlation with the values and services provided by the forest. This paper has provided an implication for designing multi-functional forest management, based on the correlation between the forest functions dynamics and the design of the infrastructures, recognized by the SES framework analysis.

Such diagnosis can open the door for developing operational tools and models that can help to better devise management strategies that takes into account the social and ecological aspects of the forest. Nonetheless, there is still to be used in merging mathematical tools (dynamical system theory, PDEs, etc.) in the framework's conceptual map which can contribute to a more generic models for the forest system.

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