



Sharing a common resource in a sustainable development context: The case of a wood innovation system

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ABSTRACT

This case study of the Aquitaine wood *filière* emphasizes the need to integrate a stronger consideration of natural resources in the analysis of innovation systems. The analysis focuses on eight eco-innovation projects representing the Aquitaine wood *filière*, and carried out under the aegis of the Industries and Maritime Pine of the Future 'competitiveness cluster.' We show that dependence on the wood natural resource can configure the limits, objectives and expected performance of such innovation systems. While previous approaches have considered similar innovation systems from territorial, sectoral or technological perspectives, we argue that centering the analysis on this natural resource better enables consideration of the technological and environmental tensions and risks that are likely to destabilize the system.

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1. Introduction

The concept of the innovation system is based on replacing the idea of innovation as an individual decision-making process, instead considering the interactions among all actors in the innovation process that comprise institutional networks within their environment [1,2]. This perspective has successfully guided new approaches to public policy. For example, in France, the "*pôles de compétitivité*" ('competitiveness cluster') policies, implemented in 2005, stem from the recognition of the need to improve the integration of innovation, industry and territory. In their second phase of development (2008–2013), they have to address sustainable development and environmental responsibility challenges.

The wood *filière* provides an example of the application of these policies. The French term wood *filière* [3,4] is used here to designate an interactive value chain, from upstream to downstream, among the subsectors of wood-based industries including the forestry, wood and paper industries and sharing a common dependence on the wood resource. The 'competitiveness cluster' policy has been applied to this system, with the emergence in 2005 of the *Industries et Pin Maritime du Futur*¹ (IPMF) 'competitiveness cluster' in the Aquitaine region of southwestern France. The IPMF has been involved in the implementation of eco-innovation projects since 2005. Eco-innovation projects include any project whose implementation is new for the actor, is likely to be a process, product or organizational innovation, and has the explicit or implicit aim to reduce environmental pollution [5,6].

This article examines the ways in which the *filière*'s strong dependence on the wood resource affects the configuration of the Aquitaine region's wood innovation system (AWIS). We analyze here the effects and impacts of the promotion of eco-innovations on a system that shares a natural resource.

Our conceptual approach departs from previous research that has attempted to link forest innovation processes with various systems models. To set these systems, these approaches have focused on their geographic, sectoral or technological dimension [7,8].

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¹ Industries and Maritime Pine of the Future. Since 2008, this organization has been named Xylofutur (for more information, please visit www.xylofutur.fr).

By situating the wood resource at the heart of our analysis, we suggest a more inclusive approach whereby the system is defined in its frontiers and in its dynamics through the sharing of a common resource. Our research highlights dynamic features of the wood *filière* within a multidimensional framework. The eco-innovation projects represent disruptions that impact the system in various ways and are likely to affect its boundaries and performance. Reciprocally, this theoretical framework also enables us to measure the effect of the wood innovation system's configuration on the directions and contents of the eco-innovation projects.

2. Theoretical framework: innovation systems

2.1. Definitions of innovation systems

An innovation system can be defined as a system — i.e., a set of interacting elements — that aims to create and diffuse knowledge allowing the production of innovations [1]. To define an innovation system, one must define the elements (actors and institutions²) that comprise the system, and the links (market relations, cooperative and conflicting relations) between these elements.

Using this definition, many authors have demonstrated the existence of particular forms of innovation systems. Following the work of Freeman on Japan [9], some authors [10,11] have applied the innovation system concept at the national level, showing that the nation constitutes an analytical framework in which the actors who produce knowledge share the same language, culture, and, most of all, particular institutional rules.

More recently, research on regional innovation systems has been based on the hypothesis that the learning and knowledge creation processes are regionally situated [12–15]. This approach is inspired by the conceptualization of districts [16], innovative 'milieux' [17] and other territorial concepts, like clusters introduced by Porter [18], while fitting into the theoretical framework of innovation systems.

By combining the systemic approaches of the innovation process and the work on technological regimes and evolutionist theories at the level of the firm [19,20], other authors have developed the concept of a sectoral system of innovation and production [21]. This concept attempts to provide an integrated vision of the structure and dynamics of a sector. By grouping actors and institutions who share the same knowledge bases through working on the same product, this approach stresses the diversity of behaviors and variety of actors trying to meet a demand (potential or effective) that emerge within the same sector of activity. It is this demand for a new product or for a new use of a product which defines the borders of the system. Indeed, as explains Malerba [21] (p.254): "differences in demand conditions play a major role in affecting sectoral differences in firm's competencies, behavior and organization."

There is some convergence between this approach and the concept of a technological innovation system, defined as a set of actors (companies, research and transfer bodies, product users) and institutions gathered around the same technological artifact or product [22,23]. This approach focuses on the final product, thereby neglecting the resource on the upstream end of the innovation system.

All of these approaches have been diversely mobilized in order to analyze the innovation processes in forestry [8,9]. However, study of the wood innovation system, based on the exploitation of a common resource, requires a broader approach than an analysis that is territorialized or focused on a technical object or industrial sector. Through our case study, we suggest a complementary vision that mobilizes all of these levels of study while integrating an additional analytical dimension of the sustainable development of a specific natural resource, the forest resource.

2.2. Characterization of innovation systems

The characterization of an innovation system proceeds in stages [22–25]. The first stage is the identification of a relevant level of analysis (e.g., a territorial or sectoral level). The limits of this system must then be determined by characterizing its components and the links among the components and the system's environment. It is also necessary to characterize the functions and objectives of this system. This stage can result in assessment of the system's performance and the recommendation of public policies that will help improve its performance.

In order to establish the relevant level of analysis and the limits of an innovation system, it is necessary to identify the actors and institutions that compose this system, and the types of relationships among these actors. The actors (individuals or organizations; particularly companies, training and research bodies or transfer-of-technology centers) and institutions (social standards, regulatory bodies) composing an innovation system will influence the system's dynamics. The links between these elements may take the form of market or non-market relations, cooperation or conflict relations. The elements of the system may also be linked by the use of a technical artifact or a common natural resource.

In the approaches presented earlier, the limits of the system are determined by geographic, sectoral or technological dimensions. For example, all companies and research bodies in a region are considered actors in a regional innovation system, and all car manufacturers and subcontractors are considered to belong to the same sectoral innovation system. We suggest a more holistic approach whereby the limits of a system are defined through the sharing of a resource that is common to all actors in the system.

To complete the characterization of components and the links between them, a system can also be defined through functions and the primary interactions among these functions. Following the definition of Johnson [26], we considered functions as relevant

² In our view, the term *institutions* applies to routines, norms, regulations and beliefs and the term *institutionalization* correspond to the creation of news routines, norms, regulations and beliefs, and not to non-firm organization.

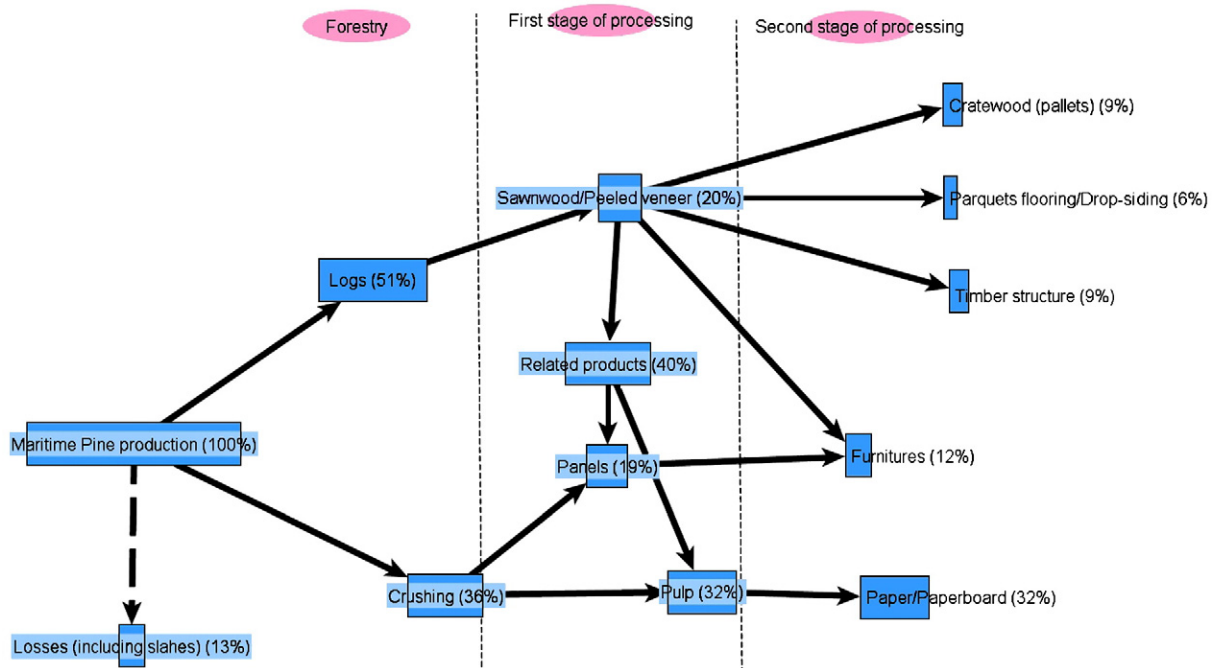


Fig. 1. The wood *filire*. The blue rectangles represent the activity sectors of the wood *filire*. The rectangles' length is proportional to the quantitative use of maritime pine resource (according to the assessments of Pajot [29]). The rectangle named "maritime pine production" corresponds to 100% of the resource, and the pulp industry uses 32% of this local production of maritime pine. The percentages of resource use are indicated in brackets within the rectangles. The black arrows represent the links (through resource use) between the industry sectors.

activities or processes that take place within the system and influence the goal of the innovation system. Thus, these activities contribute to the creation and diffusion of knowledge and innovations, thereby influencing the objectives and the performance of the system [24–26] and notably meeting market demand and creating new markets and contributing to its sustainability.

Assessing the performance of an innovation system requires the identification of indicators that enable the measurement of performance (in terms of knowledge and innovation creation) for each element of the system and for the system as a whole. Knowledge creation and diffusion may be assessed with scientific or technical performance indicators, such as the number of scientific publications, patents, or more generally the number of innovations implemented within this innovation system [27]. It is also necessary to take into account indicators of the impact of the innovation system on the territory or sector in which it is implemented. For this reason, economic performance criteria such as employment creation, turnovers and financial indicators of industries or the region may be useful. Our case study will also demonstrate the necessity of using additional indicators to assess the impact (positive or negative) on the environment and on the sustainable development of the innovation system.

System dynamics must also be integrated in the assessment of an innovation system's performance. These dynamics are created through interactions between the elements that compose the system, but also through the entry and exit of actors. They are deeply influenced by the availability of a shared natural resource, as shown in the case of the wood *filire*.

3. The context of the Aquitaine wood *filire*

The Aquitaine wood *filire* is based on the exploitation of one of the largest cultivated forest in Europe. As a "cultivated" forest, it benefits from cultivation and management techniques that are designed to ensure its continuity. While this *filire* is a classical example of an interactive upstream-to-downstream network of technical and contractual relationships, those relationships are strained by conflicts of interest among segments in a context in which it is difficult to implement targeted strategies.

3.1. A territorialized *filire* that suffers from a structural deficit of competitiveness

The Aquitaine forest covers 43% of this region, the largest degree of forest coverage among the regions of France. A storm in 2009 severely damaged the forest, reducing it to a third of its previous volume. The Aquitaine massifs forest is essentially composed of maritime pine³ species, which covers around 1.7 million ha [28]. The economic activities that finance their management, maintenance, and protection have made the Aquitaine forest a major asset for tourism and quality of life in the region. Employment

³ This forest is less diversified than other French forests: in 2006, maritime pine represented 70% of the standing wood volume (158,000,000 m³) according to Agreste Primeur, "La for t fran aise pr serve son avenir", no. 178, mai 2006.

in the wood *filière*, spread across the entire territory, represents a major contribution to rural economic activity. All of these characteristics constrain the geographic extension and production potentials of the resource. Eco-innovation projects undertaken by the system's actors, discussed below, are likely to impact these limitations.

The wood *filière* includes a variety of industries and jobs covering the first and second stages of timber processing, in addition to forest and forestry activities. These two segments work together in the first stage of processing, which includes sawmills (sawn wood, peeled veneer, planing, slicing, timber preservation) and the panel and pulp industries. The second stage of processing includes the manufacture of frames, the joinery industry, manufacture of wooden containers including pallets, furniture making and stiff paper. These elements constitute a heterogeneous set, with no capital-intensive link, different economic cycles, a diversity of uses, and a range of jobs. In the Aquitaine region, the first- and second-stage processing activities are located in the same territory, which is generally not the case in other regions of France. Timber is a heavy material with a weak added value (maritime pine is an especially difficult species to value). This low added value and transportation savings explain why the second-stage processing industries are located nearby the first-stage industries.

Fig. 1 shows the strong interactions between the *filière* subsectors. These interactions occur through wood working, and more particularly through the use of related products in each stage throughout the *filière*. Wood working is an atomized activity in which efforts have been concentrated during the last decade, but the contributions of this activity to added value and investment rates remain insufficient. This strongly contrasts with the stiff paper industry, which is dominated by major international groups and is characterized by massive investment rates and very high export rates. Within the wood working industries, only the panel industry, which is more capital intensive, maintains high performance. The furniture sector, which is slightly active in Aquitaine and mainly composed of small companies, is experiencing a deep crisis evidenced by low investment, export and profitability rates [28]. The forest-based industries of Aquitaine have maintained a good competitive positioning in France and Europe, but the challenge to be successful at the international level is becoming more important. This is apparent in three media: globalization of markets and technology; competition of new materials and products; and environmental pressure [30].

Recognizing the importance of system dynamics, the industries have answered these challenges with innovation. An average ([28] and SESSI/CIS, 2006⁴) of 22% of the sector's companies have shown innovation activities between 2004 and 2006, in comparison to 31% for all French manufacturing industries. In the forest-based industries, innovations have been mainly in process and products (26% of process innovations and 22% of product innovations). The majority of product innovations have been the creation of wood-based technical products, treated wood, mixed components development, and the manufacture of wooden beams. Process innovation, often complementary to product innovation, has focused on the development of new techniques for wood processing, because the wood *filière* uses a wide range of chemical products such as glues, resins, surfacing agents and conservatives. It also includes the introduction of optimization or simulation programs for cross-cutting and drying operations, and the implementation of processes to measure environmental pollution.

Though trying to foster its innovation processes, the wood *filière* still suffers from two structural deficits of cost and non-cost competitiveness. The small size of enterprises affects the achievement of scale economies which limits investment opportunities: on the one hand, it harms non-cost competitiveness vis-à-vis innovative countries, like Finland and Sweden; on the other hand, it impedes productivity gains and thus harms cost-competitiveness vis-à-vis newcomers like China or Indonesia. In this context, the cluster approach appears to be a unique sizeable opportunity.

3.2. A *filière* that is heavily dependent on and structured by the resource

The shape of the Aquitaine forestry system is determined by the interdependence between the renewable forest resource, the different types of actors and their interactions. Resource sharing throughout the industries is accomplished with a set of intersectoral links that is reflected in semi-finished and finished products, residuals, and recycling or valorization of related products. The initial division of labor between the timber and crushing industries conditions the relative positioning of each activity. The panel and paper industries which consume a large amount of pulpwood but also residuals from the timber industries (see Fig. 1) generally exhibit a predatory behavior toward the resources.

The Aquitaine region has typically enjoyed an abundant resource that offers a potential advantage for the region's long-term development. This advantage, however, must be balanced by the constraints of value enhancement set by the maritime pine species. This species is heterogeneous, not only because it develops in different soils, but also because it exhibits varying material quality. This intrinsic heterogeneity has been organizationally addressed by defining a specific industrial destination for each quality of tree and a specific outlet for each diameter, from thinning to clear cutting [31]. As a result, it is difficult to modify the existing balances because the nature of the resource leads to predetermined uses that have slowed the emergence of alternatives. In return, any processing that affects one element of the system is likely to affect its functioning as a whole. The inputs and outputs of actors are also a factor: inputs directly threaten the resources, and the many outputs are likely to experience a rebound effect in terms of insufficiency of related products derived from their activity. The inherent imperfections of maritime pine (poor straightness, black nodes or pitch pockets) remain a major issue in the first stage of processing. These constraints jeopardize the creation of added value usually expected from constructional timber, and in return have an impact on the other industries.

⁴ Source : <http://www.industrie.gouv.fr/sessi/enquetes/innov/cis2006/resultats.php?page=T3.html>. SESSI is the French Industry Ministry body in charge of industrial and innovation data. Industrial data are produced by SESSI on the basis of the French enterprises survey. Innovation data have been produced by SESSI since 1993 on the basis of the European version of the community innovation survey.

Table 1

Characteristics of the eco-innovation projects.

Project name	Actors: regional and sectoral dimension	Interactions across the projects	Interactions across the resource	Technology
Above	9 organisms: 6 small and medium-sized enterprises, 1 subsidiary of a major group, 1 transfer center, 1 lab - including 8 wood <i>filière</i> actors - including 8 Aquitaine region actors	Collaborative project	Strong dependence	Techniques of green wood lengthening by using wet wood gluing
Bema	10 organisms: 4 subsidiaries of major groups, 5 labs, 1 transfer center - including 7 wood <i>filière</i> actors - including 8 Aquitaine region actors	Collaborative project, exchange of equipment and staff, testing	Weak dependence (use of other materials)	Manufacture of sizes for biocomposites panels
Bioethanol	4 organisms: 2 subsidiaries of major groups, 2 labs - including 2 wood <i>filière</i> actors - including 1 Aquitaine region actor and 1 international actor	Collaborative project, equipment provision	Weak dependence	Bioethanol and pulp production techniques: using a paper process for other purposes
Bioraffinerie	4 organisms: 2 subsidiaries of major groups, 1 cooperative, 1 transfer center - including 4 wood <i>filière</i> actors - including 4 Aquitaine region actors	Collaborative project, pilot project implementation	Very strong dependence	Techniques of forestry and stump extraction, heat engines on fluidized beds: transfer of a Scandinavian technique Forest biotechnology
Biotechnologie	3 organisms: 2 labs and 1 transfer center - including 1 A – including 3 wood <i>filière</i> actors + partnerships within global research networks	Collaborative project, staff exchange (CIFRE)	Loosening of constraints on quantity and quality	
Peveco	5 organisms: 4 small and medium-sized enterprises, 1 lab - including 3 wood <i>filière</i> actors - including 4 Aquitaine region actors	Collaborative project, studies and common testing, certification	No dependence	Manufacture of paint and varnish for wood: improving an existing process
Plasmapal	10 organisms: 5 small and medium-sized enterprises, 4 labs, 1 transfer center - including 5 wood <i>filière</i> actors - including 5 Aquitaine region actors	Collaborative project, exchange of equipment and staff	Strong dependence	Processing materials by cold plasma: transfer of another sector
Sylvogene	11 organisms: 5 subsidiaries of major groups, 1 lab, 1 technical center, 4 interface organisms - including 11 wood <i>filière</i> actors - including 10 Aquitaine region actors	Collaborative project, studies and common testing	Loosening of constraints on quantity and quality	Techniques of genetic improvement for maritime pine

This table was created based on 56 semi-directed interviews conducted with actors in the wood *filière*, within the framework of a research contract realized for the Aquitaine region [32].

The annual growth of Aquitaine forest production, while considerable,⁵ is totally absorbed by the local industry. As a consequence, the panel and paper industries view any new activity, especially one using pulpwood, as a threat. For example, the emergence of the pellet⁶ industry may break the established contractual equilibrium. This system periodically generates tensions between the constructional timber and pulpwood industries, particularly when there is a potential valorization of related products, or deterioration in wood quality.

In this context, sustainable development strategies linked to eco-innovations are often put forward by the profession. Such innovations have primarily related to wood working development intended for the construction industry, and access to the wooden house market. The exploitation of the forest biomass to transform it into energy has also been addressed. These strategies aim to contribute to the objectives of energy diversification, to ensure the autonomy of the involved industries and to create a sustainable complementary activity by increasing the value of local by-products. The IPMF 'competitiveness cluster' has enabled the creation and implementation of strategies related to sustainable development through eco-innovation projects, detailed below.

4. The constrained restructuring of the Aquitaine wood innovation system

4.1. AWIS: an innovation system to be strengthened by eco-innovations implemented by a 'competitiveness cluster'

In order to determine the limits of an innovation system, the constituent actors must be identified [27]. In this study, we identified actors by using the IPMF 'competitiveness cluster.' By following the French Industry Ministry government, we used the term 'competitiveness cluster' to translate the French concept of '*pôles de compétitivité*' which are defined as "a forum for the creation of collective projects between companies, research centers and academic institutions. R&D projects are the cluster's core activity and

⁵ During the last four decades, the production of the forest has increased threefold, due to the use of fertilizers and the genetic improvement of the pines.

⁶ The pellet, or wood granule, is a cylindrical rod of compacted fuel, produced by the compaction of sawmills residuals.

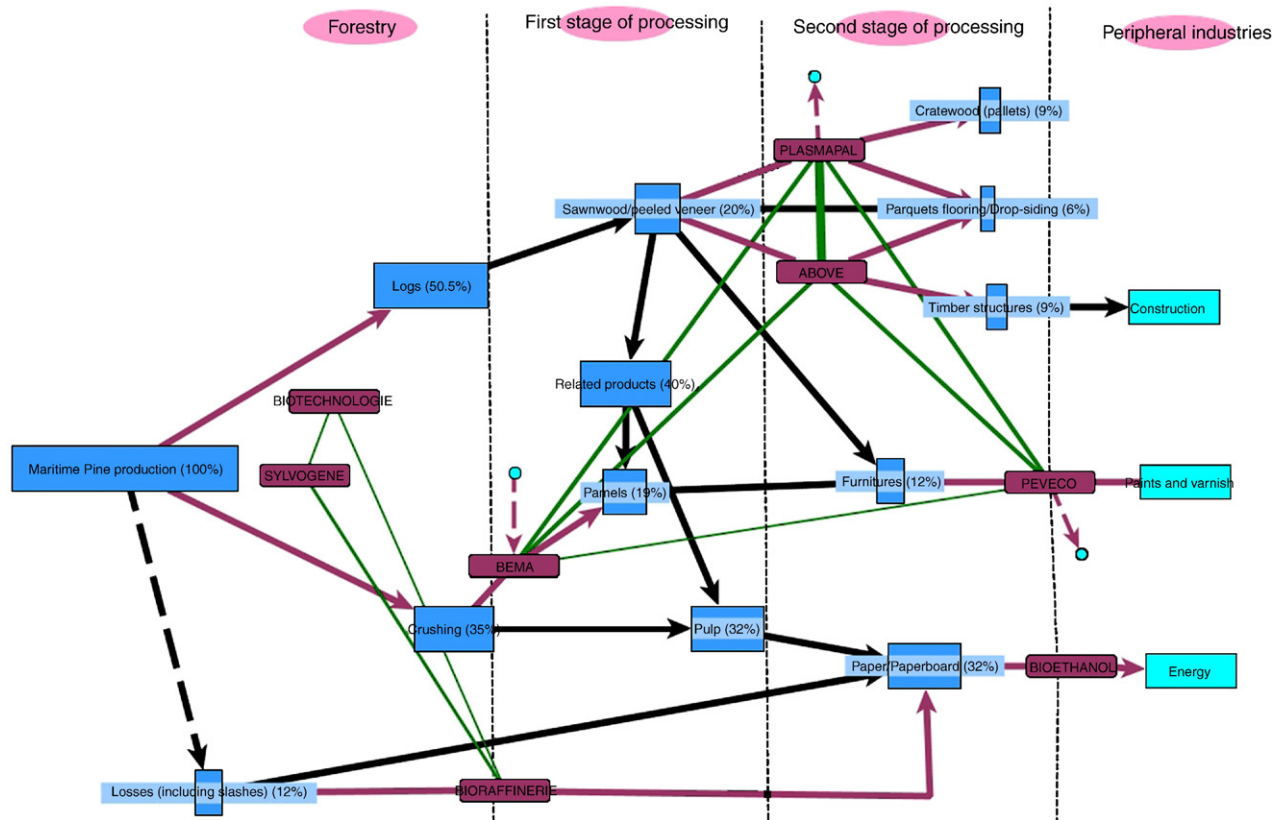


Fig. 2. AWIS and eco-innovation projects. The blue rectangles represent the activity sectors of the wood *filière*. The rectangles' length is proportional to the quantitative use of maritime pine resource. The percentages of resource use are indicated in brackets within the rectangles in Fig. 1. The black arrows represent the links (through resource use) between the industry sectors. The rounded purple rectangles represent the eco-innovation projects that we analyzed. The purple arrows represent the links between the different sectors of the chain and the research projects. The dotted purple arrows (and the light blue circles) represent the eco-innovation projects applied to materials other than wood. The green lines represent the common partners between projects. The thickness of the lines is proportional to the number of partners common to two projects.

constitute the main factor of their competitiveness. And non-R&D projects (training, property investments, ICT infrastructures, monitoring economic development, promoting local areas, international expansion, etc.) also make key contributions to the competitiveness of the cluster's companies and the local area's economic development."⁷ These forums benefit a specific governance organization, depending on the French Industry Ministry, that promotes and finances the development of research and innovation partnerships between public and private actors. They are intended to function as a laboratory of new relationships and collaborative decentralized organizations attempting, beyond the interests of stakeholders, to generate collective benefit. This definition illustrates the fact that these French 'competitiveness clusters' correspond to our precedent definition of innovation systems as a set of interacting elements (companies, research centers and academic institutions) interacting in order to produce innovations (by the intermediaries of R&D projects).

Our research is based on the qualitative analysis of the impact of eight eco-innovation projects in the AWIS that are being carried out under the aegis of the IPMF 'competitiveness cluster.' Case study data were collected through a survey [32]. The questionnaire included items concerning the actors' organizational context (company, laboratory, intermediate body), their perceptions of the significance of various innovations and environmental issues, and their characterizations of the eco-innovation projects, including their objectives and the main impediments encountered.

Following the methodology recommended in the professional and technical literature [33,34], we conducted 56 semi-directed face-to-face interviews with the main actors in the wood *filière* that are involved in these eight projects. With few exceptions, all participants in each project were interviewed⁸; this approach allowed us to examine the diverse perceptions of the different types of actors within the system. We also interviewed 10 experts on the *filière* (from regional or national bodies in charge of the financing or implementation of norms in the wood industries) in order to complete our perception of the *filière*.

Table 1 shows the characteristics of the eight eco-innovation case studies, which fall into the following groups: methodological silviculture research using biotechnology (*Biotechnologie* project) and genetics (*Sylvogene* project); development of a new technique of wet wood gluing (*Above* project); introduction of "cleaner" alternative methods to treat wood products (*Plasmapal* and *Peveco* projects); development of new wood–polymer composites (*Bema* project); and the valorisation of forestry biomass to produce bioenergy in the paper industries (*Bioraffinerie* and *Bioethanol* projects).

4.2. AWIS, an open local and sectoral system

The bodies that make up the AWIS utilize a common wood resource.⁹ Encouraged by the 'competitiveness cluster,' the introduction of new eco-innovation projects has enabled the intensification of interactions among local actors, but has also involved other sectors and industries (see Fig. 2). Fig. 2 illustrates the overlapping regional, sectoral and eco-innovation networks.

The strong congruency of these networks is partial, primarily due to collaborative projects that integrate actors not involved in the regional network or the timber sector. A secondary factor is the fact that these projects are intended for uses beyond the *stricto sensu* framework of the forest-based industries. The dynamics of the innovation system are thus open since centrifugal effects benefiting actors outside the forest-based industries and surpassing the endogenous effects may arise in the course or at the end of the collaborative project. Fig. 2 also shows that the eco-innovation projects reinforce industry dynamics by improving the resource and intensifying the density of the interaction networks among actors and activity sectors.

A dense network of small forest owners and sawyers are located upstream of the wood *filière*, most in cooperatives and interprofessional federations. About 10 subsidiaries of major internationalized groups within the panel and paper industries are situated on the downstream end of the AWIS. These groups play a central role in the dynamics of knowledge and innovation creation, and connect the local¹⁰ resource to global demand. They also provide a link between the knowledge created by local firms and laboratories and the main actors of the second-stage processing sector at the global level. In addition, they finance a part of the upstream research and implementation of eco-innovation projects.

Some medium-sized companies (200–500 employees) in the second-stage processing sector (wooden containers, parquet flooring and paneling) are also actors in the AWIS. These companies play a role in technological animation and integrate innovations into the system's dynamics that allow the 'cleaner' increase of resource value, by developing new methods of wood processing and seeking potential new uses of wood.

The AWIS also include several public research laboratories and technical centers located in Aquitaine, but involved in international scientific networks. These bodies produce knowledge through their involvement in basic and applied research activities. They also serve as experts by creating testing and certification methods for innovative products.

The final category of AWIS actors is comprised of bodies that provide financial support for innovation projects, and implementation of industrial and environmental policies at the local or national level.

⁷ More information about 'competitiveness clusters' is available on the following website: <http://www.competitivite.gouv.fr/spip.php?rubrique42&lang=en>.

⁸ We conducted 56 in-depth interviews including exhaustively all of the 40 organisations involved in the 8 project presented in Table 1. More precisely, if an organisation was involved in two projects we have made two interviews with the two individuals responsible of the projects in this organisation. Only 4 individuals refused to participate: they occupy a position of headquarters of international firms integrated in the projects ABOVE and BEMA, projects integrating each a minimum of ten organisations.

⁹ This description was informed by current awareness of the industries and through 10 interviews conducted with the main governmental bodies (e.g., regional, interprofessional federation, 'competitiveness cluster').

¹⁰ Fig. 2 shows that these subsidiaries of global panel and pulp paper groups gather most of the final output in maritime pine (15% and 25% of the local resource produced, respectively) [29].

Table 2
Objectives and performances of the projects.

Project name (phase)	Creation and diffusion of knowledge	Market demand
Above (final)	<i>Objective:</i> adapting the techniques of green wood lengthening to maritime pine <i>Result:</i> patent + other considered	<i>Market:</i> wood construction and pallets <i>Objective:</i> creation of a new market (long beams)
Bema (initial)	<i>Objective:</i> formulation and development of sizes and thermoplastic composites <i>Result:</i> patent + considered publications	<i>Market:</i> global panel market <i>Objective:</i> adapting to environmental standards <i>Spillovers:</i> transfer of knowledge (sport sector)
Bioethanol (final)	<i>Function:</i> enzymatic and microbic bioconversion of paper substrates into ethanol and use of paper manufacturer expertise to create bioethanol <i>Result:</i> patent considered + considered publications	<i>Market:</i> international market of 2nd generation biofuels and green chemistry <i>Objective:</i> transformation of pulp into bioethanol
Bioraffinerie (on-going)	<i>Objective:</i> feasibility testing, as energy source of paper sites, of biomass combustion (forest slashes) <i>Result:</i> registered patent + other patent considered + publications	<i>Market:</i> industrial paper manufacturers of the Aquitaine region <i>Objective:</i> reduction in energy costs
Biotechnologie (on-going)	<i>Objective:</i> developing techniques for selection by markers and somatic embryogenesis <i>Result:</i> patent + publications	<i>Market:</i> industrials of the chain and seed orchard market of other species <i>Objective:</i> increasing the quantities produced and improving the qualities of the product <i>Spillovers:</i> developing species cryopreservation
Peveco (initial)	<i>Function:</i> manufacturing paints or wood varnish in aqueous solution <i>Result:</i> none specified	<i>Market:</i> national wood paint market <i>Objective:</i> improving the qualities of the product and adapting the market to the environmental standards
Plasmapal (on-going)	<i>Objective:</i> adapting cold plasma techniques to wood processing <i>Result:</i> patents + considered publications	<i>Market:</i> national market of pallets, parquet flooring and drop-siding <i>Objective:</i> adapting the market to environmental standards <i>Spillovers:</i> better knowledge of the resource and transfer of knowledge (stone plasma processing)
Sylvogene (on-going)	<i>Objective:</i> implementing new techniques for maritime pine genetic improvement <i>Result:</i> new plant variety certificate + environmental risk assessment software	<i>Market:</i> industrials of the chain <i>Objective:</i> increasing the produced quantities and improving the qualities of the product <i>Spillovers:</i> developing energy wood

This table was created based on 56 semi-directed interviews conducted with actors in the wood *filière*, within the framework of a research contract realized for the Aquitaine region [32].

Historically, the wood *filière* was focused on its forest-based industries and its specific forest territory. However, the implementation of the innovation projects has intensified the recent tendency of the system to integrate external actors (i.e., in terms of activity sector, technology used, and geographic location). This cluster has also allowed more innovative activities to be integrated within the system. The limits of the AWIS are therefore broader than those of an innovation system defined by the borders of a sector, a technology or a region. AWIS actors collaborate with companies and laboratories, particularly those in the chemistry and physics sectors that are predominantly located outside the Aquitaine region. These companies and laboratories also contribute to the creation of new knowledge within the AWIS, which in turn allows the value of the wood resource to increase among second-stage processing industries. As shown in Fig. 2, this collaboration also allows the production of knowledge that is used in other industries such as construction, paint and glues, and also for materials other than wood (such as stone).

4.3. Eco-innovations attempt to increase the value of the forest resource and reinforce the existing interdependence

Through the implementation of eco-innovation projects, the main actors of the AWIS have attempted to increase the value of the wood resource. Fig. 2 shows that the eco-innovation projects have been integrated into the network of interactions constituted across the resource in the wood *filière*. Links between actors involved in different stages of resource processing have been intensified. In particular, some laboratories and small companies are engaged in several projects, thus reinforcing the network structure of the system.

New links among actors are also established through common participation in collaborative projects, leading to knowledge sharing and creation among a project's partners. Interactions within collaborative projects, however, differ in the degree to which exchanges are formalized and in the type of support required of participating bodies. Support may be financial, or may consist of sharing of technical artifacts or exchange of staff. For example, in the *Bema* and *Plasmapal* projects, technical materials are located in public laboratories but used by all project members, even by firms in competition within the same markets. Staff exchange, particularly joint supervision of doctoral or postdoctoral students, is exemplified in the *Plasmapal* and *Biotechnologie* projects, where students are supervised by firms and academic laboratories through the CIFRE device¹¹ [35]. All of these collaborative projects integrate actors from the public and private sectors.

¹¹ The CIFRE doctoral training agreement is a contract between a firm, a university research team, and a doctoral student. The firm is committed to carrying out an innovative project in partnership with a doctoral student and a research institute. In addition to a financial contribution, the firm must offer the candidate professional training (for more details about this system see Levy [35]).

The objective of all these projects is to increase the value of the wood resource, and therefore improve the dynamics of the existing system. Some of the projects aim to improve the resource on the upstream end, exceeding the natural constraints of timber while potentially increasing the amount of available resource. Downstream projects attempt to associate wood with less natural materials like plastic, in order to meet new market demands or propose more sustainable processing methods. Additionally, some projects aim to develop new uses for the wood resource.

On the whole, the network of eco-innovations adds to the existing system and contributes to its restructuring. The projects thus create a multidimensional innovation system that is both territorialized and sectoral, and also oriented by the technological and environmental dimensions. So this study confirms the previous results of Kubezcko et al. [7] about the multiple dimensions of forestry innovation systems.

The internal dynamics of the wood *filière* lead to a process of coevolution through the use of the natural resource. Such coevolution occurs not only through interactions directly concerning the resource, but also through collaborative projects and the associated exchanges of equipment and staff. Project developments thus influence the production of wood resources. In turn, resource dynamics and the strain exerted on the natural resource will influence the configuration and implementation of projects, as well as the cooperation achieved among AWIS actors, including external organizations. The process of coevolution is not restricted to the joint development of projects within the system; it also determines the conditions of the system's regulation and reorganization.

5. Objectives and performances of eco-innovation projects and the AWIS

In the next paragraphs, we will analyze to what extent the 8 eco-innovation projects may contribute to the strengthening and the fulfilment of the objectives of an innovation system for which they have been designed: creation and diffusion of new knowledge and answer to the market demand. We will complete this analysis in Section 6 by showing how these projects impact the goal of reducing uncertainty and improve sustainability of the forest innovation system. We didn't include other objectives in this paper, as these limited objectives refer to the main questions that were addressed to the actors interviewed.

5.1. Creation and diffusion of knowledge

Table 2 synthesizes the principal objectives of the projects included in this study. The aggregation of these different objectives allows the system to meet the creation and the diffusion of knowledge objective, and also the facilitation of knowledge and information exchanges. These effects occur through the constitution and organization of networks of actors, including internal, external, regional and non-regional bodies. Project performance is not well measured in terms of patents, as they are typically registered by actors belonging to other industries (e.g., chemical industries)¹² and their ambition appears rather limited (only a few ones registered and some only considered). Publications in academic journals are better performance measures in these cases. Academically oriented research laboratories have traditionally led such activity in the wood *filière*. Recently, however, very small to medium industrial companies have become strongly involved in research projects. The actors report an associated improvement in working methods; this indicates an advantage that has been gained in the processes of organizational learning, particularly because collaboration engenders unexpected interactions and new ways to create knowledge.

According to the actors, the knowledge generated in these new ways may cause breakthroughs that are sometimes “radical,”¹³ but it usually does not provoke major endogenous breakdowns in dependence on the resource. This is primarily because some projects are deeply rooted in academic research, and their practical incidences remain poorly defined. For example, the *Sylvogene* and *Biotechnologie* projects are coordinated by academic laboratories and are dominated by scientific objectives. Secondly, many projects are concerned with the geographic and/or sectoral transfer of existing processes. These transfers do not necessarily produce directly usable revenues, because maritime pine is a species that requires pronounced adaptation of the existing knowledge for other species. The creation of knowledge can take the form of a geographic transfer; for example, the *Bioraffinerie* project is derived from a transfer of Scandinavian technology for a biomass heating engine that uses wood energy. Similarly, the *Plasmopal* project is an example of an intersectoral transfer that adapts cold plasma techniques to wood processing. In most projects analyzed here, the complexity of the technological approaches requires the acquisition of expertise and its adaptation to the new context of utilization. The strong learning component also creates networks of knowledge capitalization that extend beyond the temporal framework of the project. These projects thus build knowledge and allow for the future identification and absorption of external technologies [36].

5.2. Linking the objectives to market demand

The eco-innovations examined here are characterized by a dimension of technological rupture and/or strong technological adaptation, designating them as mere *science push* projects. Their terms of completion can vary, from medium to long-term. However,

¹² According to SESSI, between 2004 and 2006, only 21.8% of innovative companies with 20 or more employees in the wood and paper sectors have filed a patent. This figure may be compared to 32.1% of all innovative companies in the manufacturing industry [28]. Source: <http://www.industrie.gouv.fr/sessi/enquetes/innov/cis2006/resultats.php?page=T9.html>.

¹³ During our investigation, we asked the actors their opinion on the degree of novelty in the projects. On the whole, 35 of 53 actors (66%) thought that the innovation was moderately or strongly novel for the market. Twenty-six actors considered that it was moderately or strongly new to the institution and 24 qualified it as a radical innovation [32].

this does not mean that *demand pull* determinants are absent, because the futures of the projects and of AWIS depend on the materialization of potential markets and on the recognition of innovation growth potentials. These markets are identified more or less precisely by the actors, and can be internal to a company or external. They are related to various sectoral systems of innovation and territorial scales (regional, national, and global). Most of the projects extend beyond the regional level, and many exceed the national level (e.g., the *Above*, *Bema* and *Bioethanol* projects include firms and laboratories located in other regions, as presented in Table 1). The targeting of international markets shows that AWIS is an open system. Obstacles must still be overcome, such as difficulties due to the unfamiliarity of some actors with remote markets or the sensitivity of these markets to changes in the price of fossil fuels.

Many of these projects depend on an industrial demand that is, in turn, highly dependent on the environmental potential of the technology. This implies that fulfilling the demand is subject to an initial appraisal of the innovation's credible success (not yet done in these cases), and to compliance with the required standards. The market is perceived as variable and uncertain, a factor that can handicap the progression of the innovation process. For example, the *Bema* project, which targets the global panel market with the formulation and development of 'cleaner' glues and thermoplastic composites, must take into account the existing environmental standards and their potential future revisions. Similarly, the *Peveco*, *Plasmapal* and *Above* projects must adapt their results to environmental standards. Appraisal of the future of these projects implies an analysis of the coevolution of uses, techniques and standards that has not to date been sufficiently implemented by the system's actors. It also implies the following two activities. First, potential clients who will use these products in their production processes must be informed of their characteristics and trained in their use. Second, the projects' promoters must try to anticipate and analyze any negative external effects inherent in the new products and processes.

Beyond meeting a pre-identified market demand, these eco-innovations may also result in retaining existing jobs and developing new ones (e.g., the *Bioraffinerie* project will directly influence the chain's activity level and indirectly affect most of the other projects by creating more than 1000 jobs). The projects can also contribute to development outside the *filière*, as technology transfer inspires confidence in the AWIS. For example, the *Biotechnologie* project aims to develop cryopreservation of plant species, and the *Plasmapal* project focuses on the adaptation of stone plasma processing to wood material.

The materialization of these direct and indirect positive effects must be viewed from the perspective of the wood resource. Because they are within the AWIS, these projects face a market that is limited by both the demand for and the supply of this resource. For example, the *Bioethanol* project aims to produce biofuel by using the ligneous biomass, a resource used by other segments of the *filière*. It therefore potentially raises conflicts among AWIS stakeholders. The creation of a new market, normally conceived as positively affecting a system's added value and openness, appears in this system as a goal whose dynamics is linked and therefore constrained by potential conflicts over resource use.

6. The environmental dimension of the system

The Brundtland Commission¹⁴ has identified sustainable development as a broader and more ethical development concept, focusing on the economic, social and environmental dimensions. Sustainable development has consequently become a central goal of the European Union. We thus now examine the ways in which eco-innovations contribute to environmental sustainability.

The eight projects included in this analysis were developed to address the insufficiencies of the wood *filière*, following pressure from regulatory bodies and society. Nevertheless, the actors often present the AWIS as an example of sustainability, highlighting the "natural sustainability" of the wood resource and also the sustainability of their practices of manufacturing "eco-products" with low transportation distances (80 km on average). This analysis assesses these statements through consideration of the eight eco-innovation projects in our sample. The main environmental objectives and expected performance of the projects are presented in Table 3.

6.1. The diversity of environmental objectives

Regulatory pressure is a source of strain on the resource. The industrial uses of wood and their negative environmental impact are in contradiction with sustainable forest management. This implies that a new balance must be found between industrial needs and resource management, at a cost that does not handicap the industries' competitiveness. In addition, the widespread use of wood in construction and building has been defined as a strategic orientation for the AWIS, which can generate tensions with the panel and paper industries. European Union legislation to encourage the reduction of emissions and polluting residuals linked to industrial activities (prohibition of chemical preservation products, VOC and REACH regulations,¹⁵ and minimization of waste quantity) has also affected the system.

The collaborative projects show varying qualities of environmental performance. They are expected to result in environmental improvements such as the reduction of polluting emissions and fossil energy consumption, and control of the economic consequences of climate disasters or fires by replacing wood with other materials. Most of the projects also aim to effect long-term

¹⁴ The Report of the Brundtland Commission, *Our Common Future*, was published in 1987. This report deals with a definition of the sustainable development as a multidimensional concept: economical, social and environmental, meeting "the needs of the present without compromising the ability of future generations to meet their own needs."

¹⁵ The VOC Solvents Emissions Directive (1999/13/EC) is the main policy instrument for the reduction of industrial emissions of volatile organic compounds (VOCs) in the European Community. It covers a wide range of solvent using activities, e.g. printing, surface cleaning, vehicle coating and wood chemical treatments. REACH is a new European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances. The new law prevails since June 1st 2007.

Table 3

Environmental dimension of the projects.

Project name (phase)	Value enhancement of the resource	Environment and standards
Above (final)	<i>Objective:</i> new uses of wood	<i>Objective:</i> reducing the losses in resource and energy consumption <i>Indirect effect:</i> substitution of renewable raw materials
Bema (initial)	<i>Objective:</i> better valorization by association with other materials, use of renewable raw materials	<i>Objective:</i> reduction of polluting emissions and adapting to regulations
Bioethanol (final)	<i>Objective:</i> new uses of wood	<i>Indirect effect:</i> substituting bioethanol for fossil energy and suppression of polluting emissions
Bioraffinerie (on-going)	<i>Objective:</i> new uses of wood <i>Indirect impact:</i> better forest maintenance	<i>Objective:</i> reducing energy consumption and adapting to environmental standards (CO ₂) <i>Indirect effect:</i> limitation of the economic consequences of disasters (climatic, fires)
Biotechnologie (on-going)	<i>Objective:</i> better increase in the value of the resource by overcoming its natural constraints	<i>Indirect effect:</i> increasing the quantities of available resources and carbon dioxide stock
Peveco (initial)	<i>Objective:</i> developing more ecologically sustainable methods of wood processing	<i>Objective:</i> reducing polluting emissions of VOC and adapting to REACH regulation <i>Indirect effect:</i> prevention of environmental and industrial risks, proactive role in regulation
Plasmapal (on-going)	<i>Objective:</i> developing more ecologically sustainable methods of wood processing	<i>Objective:</i> reducing polluting emissions of VOC and adapting to REACH regulation <i>Indirect impact:</i> proactive role in regulation <i>Indirect effect:</i> better product recycling
Sylvogene (on-going)	<i>Objective:</i> value increase of the resource by overcoming its natural constraints <i>Indirect impact:</i> adapting to climatic risks, resisting fungus damage	<i>Indirect impact:</i> increasing carbon dioxide stocks

This table was created based on 56 semi-directed interviews conducted with the actors in the wood *fil ere*, within the framework of a research contract realized for the Aquitaine region [32].

improvement in the use of the resource, whether quantitatively or qualitatively. For example, the *Above* project proposes to adapt the techniques of green wood lengthening by wet wood gluing to the maritime pine species. The goal of production increase is exemplified by the *Biotechnologie* and *Sylvogene* projects, which contribute indirectly to climate regulation through the improvement of forest production. Despite their unequal and uncertain impact, the implementation of these eco-innovations ensures in principle the general improvement of environment quality. This principle holds, despite the possibility of rebound effects compensated in more or less important ways (depending on the actors) by the impact of the substitution of wood to other materials, like plastic for example [37].

The proactive role of some eco-innovation project actors (particularly those of the *Above*, *Bema*, *Plasmapal* and *Peveco* projects) in defining the environmental regulations and standards is also important. Many empirical studies have shown the importance of the link between regulation and incentives in the development of environmental innovations, in particular the impact on the firms' competitiveness [38,39]. Proactive involvement in regulatory strategies is likely to give actors a competitive advantage [37]. These advantages were particularly mentioned by industrial actors in charge of "rupture" projects (e.g., the *Plasmapal* project) with lengthy involvement in French and European lobbying organizations concerned with industry standards.

6.2. Risks and uncertainties

Although one of the major functions of an innovation system is to reduce social uncertainty [24,25], the eco-innovation projects generate risks and uncertainties within the system's dynamics. Unlike an uncertainty, a risk can be measured [39]. Assessing the environmental performance of the AWIS requires consideration of risk reduction and alleviation of scientific, environmental, regulatory and community uncertainties.

Some projects (*Bema*, *Above*, *Peveco*, *Plasmapal*) limit industrial and environmental risks through the reduced use of chemical products that may generate industrial accidents and fires. Others (*Sylvogene* and *Bioraffinerie* projects) help control climate risks by better anticipating disasters such as storms, or by developing a more resistant resource or decision-making support tools. Those tools will enable the assessment of climate change risks and offer solutions to recover the value of the resource destroyed during disasters by converting it into alternate sources of energy.

Since most of the projects in our sample are in initial or intermediate development phases, their environmental impacts remain uncertain. For example, the impact of the planned use of nitrogen treatments by the *Plasmapal* project is unknown. The *Above*, *Bema* and *Peveco* projects are also characterized by strong uncertainties regarding the quantities of chemical products incorporated in the glues and paints used to process the wood. Several actors also mentioned the uncertainty associated with the long-term effects of stump removal and residues on soil fertility and biodiversity. These scientific uncertainties are accompanied by uncertainties regarding acceptance of these projects by foresters who are at the heart of the AWIS dynamics. Many actors fear that the strong strain on the resource could cause risks of tensions regarding its use. These tensions could worsen through the development of major industrial projects, such as the production of bioenergy (*Bioethanol* project).

The AWIS is also concerned by uncertainties in the development of environmental regulations and standards. Some of the projects in the sample are partly based on an industrial demand determined by the necessity of adapting to environmental standards. Many actors perceive the risk that these regulations will become more restrictive, which could prevent some innovations from entering the market.

On the whole, the uncertainties associated with the possible effects of introducing eco-innovations into the system make it difficult to measure the global impact of the 'competitiveness cluster' and the new forms of resource value enhancement. Predicting the environmental impact of the eco-innovations raises difficulties that are the result of unanticipated interactions between these technologies and other contextual factors.

7. Conclusion and policy recommendations

This study has emphasized the need to more strongly integrate the consideration of natural resources into innovation systems analysis. Analysis of the eight AWIS eco-innovation projects has illustrated the ways in which dependence on a natural resource exerts a deep influence on the limits, objectives and performances of an innovation system. This influence was examined at the convergence of territorial, sectoral and technological systems. The system, its actors and the innovations appear to be dependent on the resource; conversely, the resource appears to be dependent on the system's dynamics. This case study leads us to suggest the integration of a resource-based approach into research on the emergence and the roles of innovation systems. This approach also enables consideration of the sustainable development dimension in these systems.

Such an analysis also facilitates the investigation of tensions, scientific and environmental controversies, and risks that are likely to emerge. For example, the January 2009 storm that affected the AWIS illustrates the total system imbalance that can result from an environmental disaster. This storm caused destruction that harmed private producers (at the center of both the wood *filière* and the innovation system), and also public facilities (services, leisure, carbon dioxide capture). Although it severely damaged the system, the storm may also open a window of opportunities [40] that could open the system to new development paths. The implementation of eco-innovations aims to anticipate these imbalances and reduce their negative impact.

The process of institutionalization (according to the concept already defined in note 3) implemented by the 'competitiveness cluster' has been followed by a deinstitutionalization linked to the shock of the storm, further leading to a re-institutionalization process. For example, the 'competitiveness cluster' has helped the actors of the wood *filière* move from relationships of conflict toward resource sharing, and from implicit compromise to a more explicit coordination. The storm can be an opportunity to progress toward compromise and explicit agreements on resource management, which may include some coercion. Therefore, future development will focus on transforming unpredictable climate shock into forecasting and long-term planning toward multidimensional forest management.

This study leads us to recommend public policy changes for the Aquitaine 'competitiveness cluster,' in particular regarding the assessment of its performance. When only criteria related to knowledge creation and market demands are taken into account, the system remains far from sustainable development goals. We suggest a multidimensional approach to assessment that combines four viewpoints. The technological viewpoint on the feasibility, viability and compatibility of the innovations should first be considered. Second, the ecological viewpoint would allow an accurate assessment of the ecological impact of new environmental innovations. Third, we also recommend the incorporation of the economic viewpoint to measure the system's productivity, job creation, and strategic positioning in the European and global contexts. Finally, the sociological viewpoint would enable the integration of social acceptability criteria for innovations, with a particular focus on sustainable development.

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