**Territorial ecology: economic dynamics of territories through socioecological interactions, application to a French mountain village**

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| **Summary** (250 words)  [A retravailler à l’issue de la relecture par l’ensemble des co-auteurs] | Borrowing ecological principles and concepts, territorial ecology proposes to analyze the territorial (regional) dynamics and trajectories by describing the circulation of material and energy flows between human societies and the biosphere. This presentation focuses on the generation of physical, economic, social and cultural wealth through socio-ecological interactions. In order to analyze the way wealth is engendered at a local scale, a methodology has been developed and applied to Aussois, an alpine village in Savoie (France). Material and energy flow analysis combined to an analysis of the local actors’ system questions the territorial capability (ability to achieve territorial development) and resilience (ability to adapt to change). |
| **Key words** (6) | societal metabolism; industrial ecology; territory; socioecological systems |
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1. **Introduction**

At the interface between socioecological system theories and geography, territorial ecology emerges as a new disciplinary field among the French researcher community. Territorial ecology proposes to analyze socioecological interactions within a contextualized and localized area. Adopting a necessary pluridisciplinary and systemic approach, it combines biogeochemical analysis of socioecological flows and cycles, geographical approach of land use and land cover and socioeconomic understanding of local stakeholders and organizations. Resources in terms of material and energy flows, incomes as well as tangible and intangible heritage are accounted and assessed in view of their positive or negative effects on the territorial wealth generation. Retroactive effects are also considered. The system of local actors is observed in terms of physical, organizational and institutional proximity of stakeholders (Buclet, 2011, réf). Actors’ interactions are characterized through individual rationale for action in terms of power, legitimacy and interest (Mitchell *et al.*, 1997; Brullot, 2009; Brullot *et al.*, 2014). The mapping of socioecological interactions allows, *in fine*, to understand the individual and collective capability (Sen, 1999; Rauschmeyer, Omann, Frühmann, 2011, Solava, 2006).

Although this article does not pretend to address territorial ecology epistemology, it appears relevant to begin by replacing territorial ecology within the current post-growth economics framework, and especially to specify territorial ecology’s contribution to thinking and practice advances in ecological economics. We thus begin this article by highlighting how territorial ecology and ecological economics share some similarities and how they also differ and complement. This prerequisite allows putting into perspectives how territorial ecology methodology developed and applied on a case study can provide relevant insights for ecological economists. This paper then focuses on the territorial metabolism approach that proposes to analyze the generation of territorial wealth through socio-ecological interactions. The territorial metabolism approach is applied to the case study of a mountain village located in the south-eastern French Alps, through the analysis of the agricultural, the touristic and the hydroelectric metabolisms, their own interactive dynamics and the socioecological interactions linking these subsystems within the territorial system. Through this contextual and localized analysis, we will be able to question the autonomy, the resilience and the capability of the village system as a whole. Results of this applied territorial ecology analysis aims to enhance the understanding of the generation of physical, economic, social and cultural wealth in view of socio-ecological interactions, in a given geographical area. It also addresses the autonomy of actors of a geographical area in their ability to generate needed resources to meet the production of well-being. We will finally discuss the contributions of territorial ecology to economic analysis of geographical areas, to socioecological system theory and to ecological economics.

1. **Putting into perspective territorial ecology and ecological economics** 
   1. ***Similarities***

Although taking their roots into different scientific genealogies, territorial ecology and ecological economics have much in common. They share a common principle that human economy and society is embedded in the geo-biosphere and that anthropogenic processes can be conceptualized as biological, physical and chemical processes (Ropke, 2005). Human society can thus be understood and analyzed as an ecosystem. Daughter of urban ecology (Wolman, 1965; Duvigneaud, 1974; Odum, 1975) and of industrial ecology (Kneese, Ayres, and D'Arge, 1970; Ayres, 1978), territorial ecology stands for an emerging field of study (Buclet and Barles, 2013). It studies socio-ecological interactions, taking place within a geographical area (Barles, 2010). Borrowing ecological principles and concepts, it proposes to analyze the “territorial” dynamics and trajectories by focusing on the circulation of material and energy flows between human societies and the biosphere (Buclet and Barles, 2013). It constitutes a “collective of thoughts” (Fleck, 2005) gathering an interdisciplinary community of French researchers (geographers, ecologists, industrial ecologists, economists, sociologists, philosophers, among others). Beyond the perspective of neoclassical environmental economics, ecological economics is the result of a still on-going stepwise transdisciplinary process articulating ecology and economics. Among the founding steps that paved the way of the emergence of ecological economics, we can retain Boulding (1966)’s “economics of the coming spaceship Earth” Georgescu-Roegen’s bioeconomics models (Georgescu-Roegen, 1975) as well as the foundation of the International Society for Ecological Economics in 1989 which aims to facilitate understanding between economists and ecologists. Ecological economics is thus defined as a new field formed at the intersection of two older ones (Costanza, 1989). This new field has for objective to analyze jointly economic and biophysical processes and thus to examine the relationship between environmental and economic systems.

Territorial ecology as well as ecological economics has for central question the achievement of sustainable and resilient development (Costanza, 1991; Faber *et al.*, 2002; Buclet, 2015). They question the ability of natural processes and ecosystems to sustain the current trajectories of human societies. As sciences of sustainability, they share a common understanding of planetary challenges from a broad, interdisciplinary and holistic view (Costanza, 1989), articulating complexity and systemic approaches. As a science of sustainability, they are both descriptive and normative sciences (Faber *et al.*, 2002): they develop a general theory of interactions between society and environment in order to investigate how sustainable development has been and can be achieved.

As descriptive sciences, they develop methodologies and tools in order to better understand the interactions occurring between economic, social and environmental systems. Territorial ecological and ecological economics borrow to biological sciences the concept of metabolism in order to characterize the set of reactions that occurs within a system in order to maintain, reproduce, develop and interact with other systems. In the inheritance of urban metabolism (Wolman, 1965), industrial metabolism (Ayres and Kneese, 1969) or socio-ecological metabolism (Fischer-Kowalski, 1997), societal metabolism appears as a funding methodology for ecological economics in order to represent social-natural metabolic processes mainly occurring during the extraction of resources (input), during the transformation, circulation and consumption as well as during the expulsion of waste (output) (Gonzalez de Molina and Toledo, 2014). Territorial metabolism also appears as a core methodology for territorial ecology. It aims to understand the inputs, outputs and stocks embedding the territorial system, and thus to highlight interactions and retroactions processes occurring among human activities as well as between human activities and their biogeochemical environment (Barles, 2013).

As normative sciences, territorial ecology and ecological economics have for objective to provide solutions for current and future challenges. Ecological economics has for normative task to consider what is best for the public interest and the community, and therefore to maintain the preservation of the natural basis of this community (Faber *et al.*, 2002). For instance, the valuation of ecosystem services and natural capital, ecological economics can foster the implementation of fees on the destructive use of natural capital to promote more efficient use (Costanza, 1993). Territorial ecology has amongst final goals to qualify the “territorial capability” of local stakeholders. This notion of capability was originally designed by the economist Amartya Sen as the autonomy that individuals had in their ability to find ways to meet their own goals in terms of welfare (Sen, 1999). It involves the development of individual freedom, both freedom unhampered by third parties (institutional prohibitions or violence suffered by a third party) and freedom understood as the individual possibility of action to pursue the desired goals (food or clothing, social integration, etc.). Many criticisms have been made in respect of an excessively centered theory on the individual (Lessmann and Rauschmayer, 2014). They thus ignored that many answers to the needs of an individual does not only depend on his own freedom, but are produced under social and community contexts. If Amartya Sen refutes the idea of collective capabilities and prefers the idea of capabilities’ dependence to a social context, this view is contested. Authors argue on the existence of capabilities that cannot be generated without a framework for collective action (Panet-Soudron and Duray, 2008). In addition, the capability theory emphasizing the key role of freedom in the search for well-being must recognize the legitimacy of public intervention that restricts individual freedoms for the benefit of collective welfare (Deneulin, 2002). Indeed, the capabilities can be enhanced by appropriate use of ecosystem services (Pelenc *et al.*, 2014), as long as stakeholders have the means in terms of conversion into usable resources. These arguments allow considering “territorial capability” as a specific form of collective capability anchored within a territorial context. It can be defined as the autonomy of actors of a territory in their ability to generate needed resources to meet the production of well-being. Territorial ecology, through the study of territorial metabolism, can provide insights forecasting the different trajectories the territorial system can borrow depending on endogenous and exogenous variations of socio-ecological interactions, and thus to qualify the evolution of territorial capability.

* 1. ***Outstanding differences***

Although territorial ecology and ecological economics share common backgrounds and goals, some outstanding differences can be pointed out. The first difference we emphasize on deals with the understanding of the geographical space. Space analysis is not absent from ecological economics studies. Ropke (2005) pointed out the scale issue as a transversal research issue for the ecological economics community: through the development of material flow analysis or ecological footprints, the main aim is to calculate economic direct and indirect appropriation of enrgy, exergy, land area and materials, at a macro or regional level. In empirical studies, space can also be invoked through land use and land cover as a basic source of matter and energy throughput in ecosystems (Darwin *et al.*, 1996). It can incorporate space to find the ecosystem service value per hectare of various land use (Costanza *et al.*, 1997). One can also highlight occurrence of ecological economics articles addressing the issue of sense of place, understood as a subjective, emotional bond between individuals and a specific space (Clark and Stein, 2003). Hannon (1994) derives geographical discounting or humans and animals from a sense of place. Costanza *et al.* (2007) integrate sense of place as a human need to be uses as the basis for generating a set of indicators for assessing quality of life and subjective well-being. But, Lant (2009) pointed out the limitations of these approaches for a research agenda for geographers, in order to better consider the spatial relationship between human systems and ecosystems.

Territorial ecology takes geographical space, named “territory”, as the core object of analysis. Since the 1980s, social geographers use this concept in order to understand the relationship between societies and their environment: territory is designed by the eco-bio-sociologic relationships occurring between anthroposystems and ecosystems (Raffestin, 1989). Through decades, the concept of territory has become a rather polysemous concept. A minima, geographers agree that territory covers three dimensions (Laganier *et al.* 2002), i.e. i) the *material dimension* of a geographic area defined by the physical properties that can be considered as opportunities or constraints for the development of human systems, ii) the *organizational dimension* defined by social and institutional actors structured within activities, organizations or jurisdictions that embody the strategies of territorial development and iii) the *identity dimension* defined by the way social and institutional actors think and implement a project for their territory. These three dimensions can be linked in a systemic definition of the territory, defined as a complex system combining a geographic area, a system of actors and a system of representations (Moine 2006). Territory can be understood as the geographical system (i.e. a natural, social and institutionalized system) defining opportunities and constraints for human system’s organization and development. Moreover, territory is considered as a dynamic system (Moine 2006), led by political and strategic projects of management and development. In territorial ecology, territory is understood in its ethological meaning, as the results of interactions living beings – and among them, human beings – have with their environment. Territory is thus analyzed as a socioecological system (Redman *et al.*, 2004; Haberl *et al.,* 2006). The socio-ecological interactions appear as a dynamic process in which self-organized sub-systems interact: the resource system, the system user and governance. Each subsystem evolves relatively autonomously but interferes to produce results on the scale of a social-ecological system complex (Ostrom, 2009). Thus, territorial ecology proposes to define and understand the territory, through its physical, organizational and identity dimensions, as a social-ecological system (Figure 1).



Figure 1 – Territory as a socioecological system

The evolution of society can be understood as a succession of different territorial configurations, analyzed as different socio-ecological regimes that establish different patterns of interactions between society and the biosphere (Krausmann *et al.*, 2008; Schandl *et al.*, 2009). Ultimately, territory gives a political dimension to the concept of socio-ecological system, organizing and structuring a community of actors around the emerging integrated system of continuous interactions of human society with the biosphere. Territorial ecology considers the modalities of flows’ governance and the development of collaborative regional projects in order to optimize the management of flows and interactions (Buclet and Barles, 2013).

Another outstanding difference between territorial ecology and ecological economics consists in the way human beings are defined. The definition of human beings appears as an underlying debate for ecological economists. Becker (2006) provides a systematic philosophical analysis of the human actor in ecological economics, relating the evolution from the self-interested *homo economicus* defined by the mainstream economic theory to the cooperative *homo politicus* (Nyoborg, 2000; Faber *et al.*, 2002) or *homo sustinens* (Siebenhüner, 2000). He develops the concept of *homo ecologicus* in order to describe the relationship between human being and nature and characterizes it by the sympathy with and respect for nature, a creativity founded on nature and a relation with nature based on personal experience. In territorial ecology, the major difference is that human actors are considered through their individual interactions with a geographical space, a specific and localized environment, from which territory emerge. Human actors are thus considered as inhabitants (Hoyaux, 2002; Cerceau, 2013) in constant interaction with the dwelling place they share with other beings. As a result, the territorial system and metabolism can only be manifested by representations and discourses human actors have on their own interactions with their environment.

These major differences have direct consequences on the definition of socioecological processes considered in the design of the societal and territorial metabolisms. In ecological economics, these social-natural metabolic processes are understood in terms of funds and flows: funds are agents that transform input flows into output flows and have to be sustained, whereas flows include matter and energy that occur in interaction between the system and its context (Giampietro *et al.*, 2012). The territorial metabolic processes are grabbed by the concept of physical, economic, social and cultural wealth that they generate. Territorial wealth is considered as a given and a construct (Kébir and Crévoisier, 2004). As a given, wealth depends on the biogeochemical resources of the environment. As a construct, it relies on the capacity of human societies to extract and transform these resources and convert them as a potential for their development. Given resources become wealth when human societies reveal and shape their potentiality, their utility and their value (Gumuchian and Pecqueur, 2007).

1. **A territorial ecology approach: territorial metabolism of wealth generation processes**

Territorial ecology proposes to analyze each wealth generation subsystem from a socio-ecological perspective, focusing on resource units, resource system, users (or actors) and governance system (Ostrom, 2009) ().



Figure 2 – Territorial ecology methodology

Resources in terms of material and energy flows, incomes as well as tangible and intangible heritage are accounted and assessed in view of their positive or negative effects on the territorial wealth generation. Retroactive effects are also considered.

* 1. ***Identification of territorial subsystems***

Adopting a systemic approach, territorial wealth generation subsystems are defined on the basis of human time use that appears to be a determining dimension of socio-ecological interactions. It corresponds to the structure of activities and employment that are crucial factors influencing land use types and intensity, transformation of land cover and impacts on the environment (Ohl *et al.*, 2007). However, this classical economic approach, which is mainly confined to monetary aspects, does not reflect the overall wealth of a territory. Territorial wealth also includes non monetary or non quantifiable resources, for instance ecological elements that contribute to the quality of life and the physical, mental and social well-being of the population. Costanza *et al.* (2007) defined human needs which fulfillment determines the level of quality of life of individuals and collectivities. Among this human needs, the production of food and vital ecological services such as water or energy, the leisure that enables the access to nature or the homemaking. The definition of territorial subsystems thus covers socioeconomic activities that play a fundamental role in local population quality of life and well-being.

* 1. ***Collection of data***

In coherence with territorial ecology’s principle stating that the territorial system and metabolism manifest through the interaction human beings have with a geographical space, we assume that socio-ecological data can only be gathered in the oral and written discourses inhabitants produce. Territorial ecology thus design territorial metabolism on the basis of interviews with inhabitants and local documentary analysis. Among these oral and written discourses, we search manifestation of territorial metabolic processes that we characterize as endogenous and exogenous inputs and outputs that contribute to the production of territorial wealth. We identify the necessary resources and patrimony, produced or revealed by inhabitants, and we evaluate generated (positive or negative) effects on the territory in terms of wealth generation. For each subsystem, resources in terms of material and energy flows, incomes as well as tangible heritage (infrastructures, buildings) and intangible heritage (landscape, culture, identity, local skills) are accounted and assessed in view of their positive or negative effects on the territorial wealth generation.

* 1. ***Analysis of territorial subsystems***

A systemic diagram of the territorial metabolic processes is elaborated for each territorial subsystem (Figure 3). This diagram proposes a mapping of resources, tangible and intangible heritage producing or produced by the subsystem wealth generation process. On the basis of the analysis of discourses, it also allows us to map the positive or negative feedbacks related to engendered effects. We do not refer here according to the classic systemic distinction between positive and negative feedback. By positive feedback, we mean an effect of a product or impact created by the subsystem’s activity that increases in quantity or quality territorial wealth (resources, tangible or intangible heritage). By negative feedback, we thus understand the effect of a product or impact created by the subsystem’s activity that decreases in quality or quantity of territorial wealth.



Figure 3 – Territorial metabolism of subsystem’s wealth generation process

The mapping of metabolic process and retroactions allows, *in fine*, to understand the territorial capability as a specific form of collective capability (Sen, 1999; Rauschmeyer, Omann, Frühmann, 2011, Solava, 2006). Considering the ratio between exogenous and endogenous inputs as well as the density of positive retroactions, we discuss the autonomy of inhabitants through their ability to generate themselves the means to meet the production of territorial wealth.

1. **Application to Aussois, a mountain village in the French Alps**
   1. ***Case study’s description and territorial subsystems’ identification***

Aussois is a mountain village located in the Maurienne Valley in the Savoie department of the French Alps. In 2012, Aussois counted 646 inhabitants spread over 42km². The local employment rate reached 78%. Among the active population, 66,5% worked in Aussois and 31,5% within the department. Among the 372 inventoried activities, 1,1% were agricultural activities, 2,2% were industrial activities, 1,6% were building activities and 79,6% were commercial, service and transport activities including tourism (INSEE, 2013). The partition of the economy in two spheres, productive and presential, allows to better understand the logic of activities’ spatialization and to highlight the openness of local production systems. Presential activities are implemented locally for the production of goods and services satisfying the needs of persons present in the area, whether residents or tourists. Productive activities, quantified by difference, are activities that produce goods and services mainly consumed outside the area. Among the 372 inventoried activities, 60% are dedicated to the productive sphere (INSEE, 2013), which allows the hypothesis of a relative openness of the village to the regional, national and even global economy. Taking a look at the land cover repartition within Aussois communal limits (Figure 4), it appears that the urban zone is concentrated around the historical village and that the land cover is spread between forest and semi-natural areas, agricultural areas mainly covered by prairies and artificialized green areas dedicated to sports and leisure. Two hydroelectric dams and hydraulic infrastructures also occupy a remarkable place in this geographical area.



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| **Caption** | |
|  | Administrative limits of Aussois |
|  | Urban land |
|  | Forest and semi-natural areas |
|  | Agricultural areas: prairies |
|  | Artificialized green areas; sport / leisure areas |
|  | Water surface |

Figure 4 – Land cover in Aussois, a mountain village in French Alps (source: Corine Land Cover, 2012)

This time use and land cover repartitions reveal the evolution of Aussois since the beginning of the XIXth century. A historical study of Aussois socioecological trajectory (Barles, *et al.*, 2015) highlighted the evolution of the village from a relative enclaved, autonomous and self-reliant territorial system deeply connected to local resources, based on agro-pastoral activities, biomass energy (wood, charcoal, animal heat and feces) as well as human and animal labor to the opening of the territorial system under the influence of exogenous factors. Until the end of the XIXth century, the dwelling dynamics and configurations were mainly based on the human capacity to mobilize vital resources (Préau, 1984). In the 1950s, the construction of the hydroelectric dams fosters the industrialization of the valley, having for local consequence a massive exodus of Aussois labor force and the decline of the agro-pastoral system. Hydroelectricity also led the transition from biomass energy to electricity and fossil fuel energy. The internalization of industrial and hydroelectric incomes in the village’s economy allowed the development of touristic activities, and especially in the 1950s, with the building of a communal ski station still operating today (Galléty, 1983). Pluri-activity (agriculture, tourism, and industry), high mobility and importation of goods and services contributed to disconnect the territorial system for local resources. Dwelling dynamics and configurations are now based on residential and touristic attractiveness (Préau, 1984).

This brief description of Aussois territorial and historical context allows a better understanding of the methodological choices taken to identify the local territorial subsystems. In this case study, four wealth generation subsystems have thus been identified (Table 1): the agricultural subsystem, the hydroelectric subsystem, the touristic subsystem, but also the residential subsystem (people living within the perimeter of analysis with revenues not depending of the territory: commuters, retired, out of work...). The analyses of the agricultural subsystem, of the hydroelectric subsystem and of the touristic subsystem are detailed in the following sections.

Table 1 – Identification and characteristics of territorial subsystems in Aussois

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| --- | --- | --- | --- | --- |
| **Territorial subsystems** | **Percentage of the economic basis of the district\*** | **Employment\*\*** | **Land use\*\*\*** | **Quality of life\*\*\*\*** |
| Agricultural subsystem | 9,2% | 1,1% | Agricultural land (including prairies):  46% | Subsistence |
| Hydroelectric subsystem | / | / | Water surface:  1,3% | Subsistence |
| Touristic subsystem | 50% |  | Semi-natural and forest lands:  52,1% | Leisure |
| Residential subsystem | 24% |  | Artificial land:  0,6% | Homemaking |

\* Source : Magali Talandier, from DGI, RGP-Insee, Dads-Insee, Unedic, BDSL, DGCIS data basis

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\*\*\* adapted from Corine Land Cover, 2012

\*\*\*\* From Costanza et al., 2007

Results of this case study analysis are based on the analysis of local actors discourses collected through 25 semi-directive interviews in 2013-2014 (Table 2) as well as on the analysis of local documentary archives and research works. The representativeness of the qualitative analysis sample cannot be assessed on statistical grounds (Miles and Huberman, 2003). It deals with theoretical saturation and the sample’s capacity to develop and consolidate the theorization process.

Table 2 – Panel of interviewed local actors distributed according to the territorial subsystems



* 1. ***Agricultural subsystem’s metabolism and capability***

Mainly based on extensive forms of stock faming such as the breeding of dairy cattle for Beaufort cheese production, the agricultural subsystem appears as a structuring component of the territorial wealth generation system. Agricultural subsystem has undergone profound transformations between 1950 and nowadays. Until the mid XXth century, the agricultural subsystem appeared as a relatively closed system (mainly depending on local resources and maintained through numerous inner retroactions). Since 1950s, the multiplication of outdoor interactions led the agricultural subsystem to a greater dependency, questioning its capacity to maintain its capability and resilience. The increase in external flows substantially modifies the traditional endogenous activity, the agricultural subsystem becoming strongly connected to the international market. Figure 5 highlights the place occupied by externalities in sustaining agricultural activity that is dependent on many external inputs related to additional incomes through pluri-activity, to fossil fuel energy for mechanization, to the use of fertilizers and pesticides (even if the latter is limited by the technical specification of the Beaufort labeling). The localization of Aussois, below the hydroelectric dams, allows an abundant irrigation of productive hayfield, which appears to be exceptional, compared to climatic constraints that Alpine farmers are facing in other villages (EEA, 2009; Meyer and Sinabell, 2011). The main feedback within the subsystem essentially concerns pollutants or monetary flows, in a configuration where, in addition in France, subsidies are vital to the agricultural subsystem mainly structured according to these aids.

This subsystem is also characterized by a reduction in the local output stream, another element indicative of any connection between this subsystem and the territory, in favor of a stronger interaction with the rest of the world. Nevertheless, the agricultural system plays a key role through the intangible and non-monetary services it provides to the territorial system: it maintains the landscape and the natural environment, including the prevention of shrub and reforestation and, but also for the maintenance of open habitats. These induced services are not being evaluated, despite the fact that they represent a cost and therefore a significant annuity as it has been shown for other ecosystems and other agricultural landscapes (Wainger and Mazzotta, 2011; Laurans *et al.*, 2013).

Similarly, in the village landscape, traditional dwellings, which represent an attractive legacy of the architectural heritage, not longer incorporate agricultural activities that were rejected and concentrated in an area dedicated to the agricultural buildings, barns, and equipment freeing space for a better management of nuisances and pollution related to agricultural waste. The agricultural subsystem also plays a key role through monetary incomes it provides to the territorial system: the high quality Beaufort production allows sustaining high exportation incomes, the liter of milk being sold twice the price it is sold elsewhere.



Figure 5 – Agricultural subsystem metabolism

In terms of territorial capability, we propose to analyze the progressive organization of farmers in a process of certification as a collective process for the sustainability of high mountain wealth generation. For the agricultural subsystem, this capability expresses the fact that it can perpetuate itself by the establishment of a system of production and organization allowing farmers to live from agriculture: “what is needed is that people manage to live from it” (extract of an interview with a farmer). Facing the productivist tendency incompatible with mountain production conditions, farmers have played the card of cooperation and quality in order to increase the valuation of milk.

**Resources**

**Functionings**

**Capability**

Low local labor, competition of other local cheese production

Will to maintain ancestral skills

Increased quality, of production, increase in sale prices and promotion of Beaufort product via the AOC

Manage to live from high mountain agriculture

Figure 6 – Analysis of the agricultural subsystem in terms of capability (adapted from Sen, 2002)

* 1. ***Touristic subsystem’s metabolism and capability***

Aussois is part of an alpine environment that has fully integrated the dynamics of tourism growth in the XXth century. However, Aussois is distinguished from other alpine stations by maintaining a dynamic winter tourism activity favored by its abundant and inexpensive water and energy resources related to the hydroelectric infrastructure. Indeed, Aussois can use large quantities of water and energy to produce artificial snow during the ski season, whereas meteorological conditions are unfavorable due to the impact of climate change (Meyer and Sinabell, 2011). This exceptional configuration ensures a winter tourism activity where other mountain communities are facing a drop in snowfall and an increase in the cost of energy. The diagram of the touristic metabolism (Figure 7) reflects the fact that the touristic subsystem is very interdependent, articulating many resources and many local stakeholders through many tangible and intangible flows and interactions.

The main flows are represented by tourist traffic. In 2012-2013, 147 100 tickets for ski lifts were sold. The commercial accommodation counts 945 beds in 2012. In 2013, there were 16 food establishments. The tourist subsystem is a major consumer of materials incorporated into infrastructures such as ski lifts, pylons, cables, platforms, etc. The accommodation facilities require an important electric supply that Aussois can spend generously thanks to preferential pricing due to the presence of hydropower infrastructures. The seasonal touristic presence increases the demand for consumer products including food, partially supplied locally by a bakery and two points of supermarket type of sale.



Figure 7 – Touristic subsystem metabolism

This results in import flows of raw material such as retail products. The dairy cooperative Aussois also benefits from tourism: 75% of its revenue depends on sales to tourists. Beyond that, the landscape stands among the carriers of the tourist subsystem throughout. Tourism also generates output flows, including waste. The wastewater treatment plant of Praz, which is largely financed by Aussois local authority thanks to tourism, gathers liquid wastes. Tourism generates substantial local monetary income, for the local authority, for touristic professionals but also for a major part of the population: touristic jobs appear as seasonal income complement for farmers and attract workers from the valley.

The tourist subsystem is the main source and lever of wealth creation in Aussois. This can be evidenced by the numerous feedbacks among the touristic subsystem and with other territorial subsystems: for instance, the touristic entropy and external real estate acquisitions have for consequence a substantial increase of local taxes and of the square meters cost; touristic activities impacts the development of other local activities and participates in local services, which allows maintaining the "village" character of the resort that attracts tourists in return; agriculture maintains the “post card” landscape of Aussois which means a lot to tourists but also experiments use conflicts with summertime touristic activities.

Figure 8 – Analysis of the touristic subsystem in terms of capability (adapted from Sen, 2002)

The interdependence of other activities with tourism can be experienced at the individual and at the collective scales. The capability related to tourism far exceeds the objectives and interests of the sole tourist community (Figure 8). For the majority of local actors, the expression of this capability can result individually by the capacity to continue living in Aussois, to sustain this lifestyle, and to continue to live collectively in the village whose economic heart remains tourism. Individual capability is related to the collective capability: it is only by continuing to live in the village that actors can sustain their current lifestyle. To do so, local stakeholders have existing resources that must be maintained and developed:

* Individually, by increasing touristic activities in order to live or live better in Aussois "multi-activity is the rule in High Mountain" (extract of an interview with a mountain guide).
* Collectively, by the extension of accommodation capacities, the development of summer tourism and the expansion of the ski domain.

This deep embeddedness of the touristic subsystem within the territorial wealth generation system questions the vulnerability of Aussois, facing economic consequences of a crisis in the touristic sector or external constraints (especially National Park charter) burdening on the development of local touristic activities. This can explain the willingness of local actors to maintain local control over land management, choices in terms of economic development and on all the levers able to sustain this source of wealth creation.

* 1. ***Hydro-electric subsystem’s metabolism and capability***

We focus here on water resources as a factor of wealth creation, mainly through the development of the hydroelectric industry. Water also plays a major role, both for the development of agriculture and its related activities as well as for tourism. However, it is when water use is devoted to the production of energy that it can generate a territorial wealth. We need to distinguish two main "water regimes": 1/ until 1952 (commissioning date for the Aussois hydroelectric power plant), the use of the abundant water resource was primarily for the development of farming: “The main goal of irrigation was not cultures but hayfields. We had to water them to improve the yield of grass” (translated from Meilleur, 2013); 2/ since 1952, this "traditional" water use becomes marginal in regard to the development of the hydroelectric industry. Water resources become a more direct source of revenue for the town territorial system through the building of two dams and the hydroelectric power plant that generated temporary employment, and mainly through the business tax paid by the national electric company and the benefits derived from access to preferential rates for water and electricity.

Nowadays, the main inputs to the socioecological metabolism are building materials and labor force for the maintenance of existing infrastructures. As for the outputs, the hydroelectric activity introduces changes in the landscape and in the traditional structures irrigation and use of water power. But, hydroelectricity essentially generates monetary flows received by the municipality (business tax, profits from the local electric service) and more marginally by its inhabitants (savings on the price of energy). Intangible flows must not be neglected: on the one hand, a proactive national policy fostering hydropower development and driving locally the strategy of investment, on the other hand, the development of technologies and skills by local stakeholders in order to maximize local benefits of this activity (Figure 9).



Figure 9 – Hydroelectric subsystem metabolism

From the point of view of territorial capability, the national intervention at a local scale could have induced a reduction of the local autonomy in terms of energy and water management. But, the local management of these resource and the derived benefits allow local stakeholders to maintain a control on the territorial wealth generated (Figure 10).. Indeed, the structure of the socioecological metabolism of the hydroelectric subsystem in Aussois shows a relative opacity which makes it difficult to qualify and quantify all the interactions between the different actors of the activity of production and distribution of water and electricity. This opacity can be understood as the guarantee of a local control on this activity, also strongly governed by regulations and contracts with the national electric company. A single positive retroactive feedback has been identified and shows how the system is self-reinforcing: the electric service of the municipality that provides energy to the ski station generates benefits that are later feed back to finance the operation and maintenance of ski lifts

Figure 10 – Analysis of the hydroelectric subsystem in terms of capability (adapted from Sen, 2002)

* 1. ***Territorial metabolism***

However, the analysis of each subsystem delivers a partial view of the territorial system as a whole. Being densely embedded, interconnected and interdependent, they need to be articulated within a territorial system of wealth generation. Territorial ecology proposes to analyze these inter-subsystem interactions in analogy with biological ecosystems. The territorial subsystems demonstrate several types of interactions or symbioses, which effects can be positive and / or negative. We borrow to ecology the concepts of mutualism, commensalism and parasitism to describe the symbiosis between the different subsystems designing the territorial system (Figure 11).

In the case of Aussois territorial system, we can highlight two mutualistic symbioses. The first one concerns the touristic and hydro-electric subsystems. The hydro development enabled the touristic development thanks to the financial capacity newly acquired by the municipality, allowing it to invest in the development of a fully equipped ski resort. In return, this touristic activity introduces change the terms of water management by the increased water demand generated by seasonal tourist influx, and by the development of a snowmaking capacity (Marnezy, 2003). During the touristic season, the resident and tourist population of Aussois rises from approximately 700 inhabitants to about 5,000. This has consequences on the volumes of water consumed and of waste water. This induces an over-sizing of the waste water treatment plant. In addition, a composting platform has been designed to value the sewage sludge. This sludge, mixed with green waste, allow the production of compost used for the revegetation of the ski slopes, which makes it easier to keep the snow in winter. The second example of mutualistic inter-subsystems’ interactions concerns the agricultural and the touristic subsystems. Indeed, the agricultural system plays a key role through the intangible and non-monetary services it provides to the touristic subsystem: it maintain the landscape and the natural environment, including the prevention of shrub and reforestation both for winter touristic activities, contributing to the maintenance of ski slopes, but also for the maintenance of open habitats favorable to the attractiveness of mountain landscapes.

Finally, Aussois territorial system evidence one case of parasitic symbiosis. It can be found between the agricultural and the hydroelectric subsystem: the Beaufort cheese production and the expansion of the cattle herd reveal forage supply difficulties requiring an increased forage production on the alpine grasslands (PNV, 2013). The issue of irrigation is therefore to increase the yield on existing land and thus to limit imports of hay, by the extension of the water irrigation network and the organization of an irrigating collective among farmers. Despite the relative abundance of water, the territorial water subsystem thus shows a strong pressure on the resource.



Figure 11 – Territorial system: interactions between the agricultural, the touristic and the hydroelectric subsystems

This intertwining of subsystems offers a systemic vision of the territorial capability, understood as the ability of local stakeholders to find and seize material and immaterial resources to develop their territory. In interaction with their environment, local societies maintain and develop each subsystem taken independently as well as territorial system as a whole, by creating wealth interactions in which these components fit together. Territorial ecology intent providing a systemic view of wealth generation in which the territorial wealth is seen as wealth produced both from natural resources available in the environment and resources built by individual and collective learning of human societies.

1. **Discussion**
   1. ***A complementary vision to the economic analysis of territories***

The economic analysis of territories has for long invested the issue of identifying the major current sources of income and employment within a local area (réf). The challenge is to take into account all the wealth generation flows that irrigate a local area. Beyond the productive activities of exported goods and services outside of the considered area, the economic analysis of territories must also take into account other sources of income that are not directly generated by the production. Tourists’ spending, commuters’ wages, pensions, salaries of civil servants, various allowances, welfare benefits and services are considerable revenues that foster local economies regardless of their ability to produce and export goods and services. In economic base theory, this residential base is thus added to the productive base and allows considering the overall economic base of the territory (Davezies, 2008; réf). Such approaches led researchers to assess the potential of non-monetary items, such as the landscape, as a factor for local wealth development (Dissart and Vollet, 2011).

This economic base approach has been established at the scale of Terra Modana, the district area including Aussois among its 7 cities and villages (Table 2). It decomposes territorial economy into two sectors: the basic sector which captures revenue from outside the area and the domestic or presential sector which produces goods and services locally required (réf). The drivers of development are linked both to what the territory is able to produce and export, and to what it is able to capture, especially because of its residential and recreational attractiveness.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Terra Modana (€/capita)** | **Terra Modana (%)** | **French district average (€/capita)** | **French national district average (%)** |
| Productive base total | 1 894 | 9.2 | 2 381 | 15.9 |
| Domestic base total  *Including touristic spending* | 15 297  *10 281* | 74.4  *50.0* | 8 323  *1 876* | 55.5  *12,5* |
| Other (public and sanitary bases) | 3 377 | 16.4 | 4 285 | 28.6 |
| **Economic base total** | **20 568** | **100.0** | **15 989** | **100.0** |

Table 2 – Economic base estimations for Terra Modana district in 2006 (Source : Talandier, from DGI, RGP-Insee, Dads-Insee, Unedic, BDSL, DGCIS)

In Terra Modana, the total productive base weight just over 9% of the territorial basic income (which is less than the 16% average for the French districts). In comparison, we note the considerable weight of the residential economy which represents ¾ of the collected and created revenue. This can be explained by the weight of touristic spending (50% of the total economic base) which rate stands among the highest in France. Tourism is certainly not the only source of income, but its weight is undoubtedly the key driver of this district. If we consider the bases calculated in €/capita, the supremacy of the touristic base (five times higher than the French average) is accompanied by a lower per-capita productive base (20% lower than the national average). Thus, tourism has not completely driven out the other productive activities of the area.

Territorial ecology provides relevant complementary insights for a economic base analysis. It allows the identification of non-monetary flows (namely intangible heritage) that may not be taken into account in such an analysis. These non-monetary flows such as landscape, traditional knowledge and skills or notoriety pave the way for further developments in taking into account the quantitative weight of these heritages in the territorial wealth generation. Moreover, territorial ecology allows the identification of interactions occurring between the different economic bases, highlighting the fact that incomes generated by one economic base can benefit or constrain another economic base. This questions the possibility to quantify the transfers of wealth occurring between different territorial subsystems.

* 1. ***A complementary approach for long term socioecological research***

Since the middle of the 2000s, researchers have worked to integrate socioeconomic issues in the analysis and understanding of long-term ecological patterns and processes. Long-term socioecological research thus proposes to focus on the integrated systems that emerge through the continuous interaction of human societies and ecosystems (Redman *et al.*, 2004; Haberl *et al.*, 2006). As the analysis of Aussois case study showed, territorial ecology needs to refer to the historical and dynamics processes. The evolution of societies can be understood as a succession of different socio-ecological regimes that establish different canvas of interactions between society and the biosphere (Krausmann *et al.*, 2008; Schandl *et al.*, 2009). Technological change and energy, economic developments, political changes or resource shortages have significant impacts on the evolution of social-ecological interactions and they challenges the resilience of the systems on a local scale (Haber *et al.*, 2006, and Mathevet Bousquet, 2014). The challenge of territorial ecology is to re-register these findings often set at a national level, at the local level of a specific territory.

Long-term socioecological trajectories are often characterized in terms of quantitative socio-metabolic transitions characterized by GDP, energy sources and flows, technological changes, land use, working time (Krausmann, *et al.*, 2008; Krausmann and Fischer-Kowalski, 2013). The geographical area under study can be at a national or at a regional scale and is often considered as a “black box” crossed by input and output flows. Defining different subsystems at a local scale, and identifying inner-subsystem retroactive interactions and inter-subsystem symbiotic interactions, territorial ecology proposes methodological inputs to open the territorial “black box”. This approach allows 1/ analyzing socioecological transitions in terms of changes in the subsystem retroactions (i.e. transition from a subsystem characterized by a high density of internal interactions to a subsystem defined by a high density of external interactions), 2/ describing how the territorial system is modified by changes in the symbiotic interactions occurring between subsystems (i.e. transition from a resilient territorial system characterized by mutualistic intertwining of subsystems to a vulnerable territorial system characterized by competition between subsystems) and 3/ arguing on the endogenous and exogenous causes of socioecological trajectories.

* 1. ***Conceptual and methodological inspiration for ecological economics***

Conscious of similar challenges and pursuing comparable goals detailed in section 2, territorial ecology and ecological economics borrow different narrative pathways to sustainability, different ways of understanding and representing the socioecological system underlying different scientific storylines (Leach, 2011). Nevertheless, to be able to serve as base for societal development strategies, territorial ecology can be useful for ecological economics, especially to provide conceptual and methodological inspiration and guidance to ecological economics’ effort for a contextual analysis that can adapt to changing temporal and spatial scales of analysis and policies (Andeberg, 1998).

As we argued in section 2.2, ecological economics mainly addresses the issue of space and scale by considering the embeddedness of social system within the biosphere or the co-evolution of ecological and economic systems linked in time and space (Ropke, 2005). Territorial ecology proposes to approach the issue through the concept of territory understood as the emergent property resulting from interactions occurring within a socioecological system. Taking territory for object of analysis, territorial ecology invokes a theoretical framework borrowed from geography and ecology. Addressing these interactions through the concepts of land use and time use, territorial wealth and capability, it proposes innovative tools to grab these socioecological interactions. We are convinced that these tools could be usefully appropriated by ecological economists.

Another input for ecological economy can be found in the way territorial ecology defines human beings. As detailed in section 2.2, ecological economics conceptualize human actors in different and even divergent notions. This debate raises the fundamental question of the deterministic or non-deterministic explanation of human behavior (Siebenhüner, 2002), inherent in all disciplines whose core principle is the embeddedness of human system within the biosphere. By defining human actor as an inhabitant, territorial ecology proposes an issue to this aporetical debate. As inhabitants, human actors are by definition deeply embedded in a geographical space or an environment and determined by bio-geo-chemical constrains and opportunities. But they have the possibility to choose, among these opportunities and constraints, the way they exploit this bio-geo-chemical context and thus the direction they want to give to their pathway of development and transformation (Berque, 2010; Berdoulay and Soubeyran, 2013). It thus participates of human actors’ free will. Putting inhabitants at the center of its methodological developments, through the analysis of the way human actors represent and narrate their relationship with their environment, territorial ecology proposes a way to grab these socioecological interactions and the possibilities or capabilities, they offer, and to model them in terms of socioecological metabolisms.

These elements of discussion may be in line with a phenomenological understanding of ecological economics. Ramos-Martin (2003) argued that ecological economics is representative of a phenomenological approach as it defends that all understanding regarding a system or a process is context dependent. He analyzed recent empirical work in the field of ecological economics in that perspective, showing how different variables of the societal metabolism are analyzed, without any deterministic forecasting, in order to find underlying characteristics of the considered systems. Territorial ecology proposes to extend this phenomenological approach to the very design of the socioecological metabolism: it defines the territory as the interactions between human actors and their environment, and thus can only grab the territorial object through the human representations and narratives. As a result, territorial ecology invites ecological economics to test the relevance of being not only context dependant but also actor dependant.

1. **Conclusion** [A rédiger à l’issue de la relecture par l’ensemble des co-auteurs]

Synthèse des principaux résultats

Mise en évidence des limites de l’approche décrite pour répondre à l’objectif de contextualisation et agendas des futures recherches en écologie territoriale : besoin en termes de quantifications (liens avec les travaux sur les services éco systémiques, lien avec les travaux d’ACV territorial, etc.), meilleure intégration des acteurs dans le processus de création de connaissances territoriales

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**Appendix – Extract of interview guidelines (if needed)**

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