



Analyzing the vulnerabilities and capabilities of wealth creation activities in the Maurienne valley in the French Alps

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Abstract

Alpine valleys constitute fragile environments and are very sensitive to environmental change. Current trends constitute major upheavals challenging these communities' adaptation abilities. Coupling quantitative modeling and qualitative social sciences analyses is necessary to provide insights on sources of vulnerability but such endeavors remain rare in the scientific literature. We present a metabolism-capabilities-vulnerabilities framework, which describes local communities and their environment as a network of wealth creation activities. We apply this framework to one of the main farming activities in the Alpine valley of Maurienne, the production of Beaufort cheese. We describe how stakeholders are involved in the supply chain and then quantify the economic and environmental aspects of the flows. We introduce the concept of "territorial capabilities" to analyze the ability of stakeholders to cope with change through a reorientation of their activities. We highlight that while current environmental pressures do not seem to exceed local environmental limits, climate change is likely to be a source of future vulnerability. On the socio-economic side, the analysis points out the dependence on subsidies and the aging of the workforce as other potential threats to this activity. Conversely, the local cooperatives system appears to be the main asset in vulnerability reduction.

Keywords Vulnerability · Capabilities · Metabolism · Material and economic flow analysis · Environmental assessment · Adaptation · French Alps

Introduction

Global change challenges the sustainability of human activities in socio-ecological systems and several vulnerability frameworks have been devised to characterize them on this front. For example, Adger (2006) defines vulnerability as the susceptibility to harm from exposure to stresses associated

with environmental and social change, and from the absence of adaptation capacity. Füssel (2007), on the other hand, characterizes vulnerabilities along four dimensions: the system of interest, the main attribute of concern (what is valued and threatened), the hazard or stress under scrutiny, and the temporal reference (e.g., short or long term).

When applied to *territoires*¹ or local communities, these generic definitions and characterizations lead to two broad lines of analysis. The first one focuses on specific types of stresses or hazards. For instance, the vulnerability of mountain communities and mountain farming to climate change and natural hazards is often pointed out (Deléglise et al. 2019; Shukla et al. 2018; Birkmann et al. 2013; Fuchs 2009). The second one, conversely, starts from the functioning of a *territoire* in order to identify potential sources

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¹ A synthetic definition of a *territoire* is a delimited geographic area considered as a collectively constructed network of relations and as a shared living environment (Cunha 1988). The French concept of *territoire* reflects this meaning much more closely than the English "territory" does, and in this article, we usually keep the French wording to stress the distinction.

of vulnerability. This second approach seems much less common, in spite of its usefulness for stakeholders. Wilson et al. (2018), building on Emery and Flora (2006) and Kelly et al. (2015), argue that higher levels of development of the social, economic, cultural, political, and environmental spheres of activity make communities less vulnerable. More generally, Sharifi (2016) conducted a review of community resilience tools, mostly targeted on urban areas. According to this author, though, current community resilience tools have failed to account for cross-scale or temporal dynamics and environmental dimensions.

Two research gaps in the vulnerability literature motivate this article. First, few studies have analyzed territorial vulnerabilities from a metabolic perspective, i.e., based on the study of material and/or energy flows (MFA). Bahers et al. (2019) explicitly introduce the notion of metabolic vulnerability in the context of islands. While environmental vulnerability “*questions a society’s ability and preparedness to cope with brutal changes in its environment, metabolic vulnerability focuses on the effect of these perturbations on resource circulation, from extraction and production to end of life as wastes, between consumer areas and resource-supplying or waste-disposal areas.*”² This point of view seems promising to provide a complementary perspective on vulnerability. Second, while the necessity to address sustainability issues in a transdisciplinary way is largely recognized, endeavors that explicitly take into account the role and interactions of local actors in flow circulation remain rare in metabolism studies (such as, e.g., Binder 2007a, or Dijkstra et al. 2018). Conversely, *territoire* studies — focusing for instance on the relationship between value chains and territories (e.g., Muchnik et al. 2008; Paus and Reviron 2010; Fares et al. 2012) — seldom address to a sufficient extent the environmental and biophysical dimensions of the systems analyzed (Madelrieux et al. 2017).

In this article, we argue that coupled quantitative metabolic and qualitative territorial analyses lead to a better understanding of the coupled social, economic, and ecological vulnerabilities of a *territoire*. Our goal is also to inform stakeholders on their *territoire* vulnerabilities, and point out relevant factors to enhance capabilities (Sen 1999), in order to effectively cope with related weaknesses. Our endeavor builds on previous work in territorial ecology (Buclet 2021). This emerging field in France attempts to bridge the gap between social-ecological system (SES) studies and *territoire* studies, the latter finding their origin in social geography. Territorial ecology is also related to the Vienna school of social ecology (Haberl et al. 2016), with however more emphasis on stakeholders’ roles and territorial dynamics.

The Maurienne valley in the French Alps was chosen as a case study. Alpine valleys constitute fragile environments, are very sensitive to environmental change (Fuchs 2009) and have undergone vast socioeconomic changes in the past decades (Zucca 2006), challenging these communities’ adaptation capacities.³ Our case study bears on a single activity, namely the Beaufort cheese production, with some focus on its relation to territorial dynamics and on trade with the rest of the world. This choice is motivated by the fact that agriculture in general and cheese production in particular is a structuring wealth creation activity in a number of Alpine valleys. This activity contributes to the territorial identity of the Maurienne valley and plays a decisive role in the maintenance of the valley landscape and the level of local employment (Buclet et al. 2015). In other words, Beaufort production stands at the cross-road of the material, organizational, and identity dimensions of the *territoire*, in interdependence with other local activities. Therefore, focusing on this single value chain is not detrimental to a territorial perspective.

Conceptual approach

The cornerstone of the metabolism-capabilities-vulnerabilities (MCV) framework adopted here is to characterize a wealth creation activity (WCA) by its metabolism, encompassing both quantitative (material and energy flows, environmental pressures, monetary flows, infrastructures, land use, environmental assets) and qualitative dimensions (stakeholders’ relationships and motivations/goals, cultural and institutional contexts). Some interactions with the rest of the world and with the other WCAs of the *territoire* are also considered. In this way, we are able to assess territorial capabilities (defined as the stakeholders’ capacity to identify common goals and to meet them collectively, see “**Territorial capabilities**”) and vulnerabilities (Section “**Vulnerabilities**”). Finally, we qualitatively analyze the interactions between territorial capabilities and vulnerabilities: in what way do territorial capabilities enhance the *territoire* adaptive capacity and therefore reduce its vulnerabilities? Conversely, how can vulnerabilities undermine territorial capabilities?

Figure 1 illustrates the MCV framework and its conceptual connections. In this work, we do not analyze in detail all the elements listed in this figure; The “**Material and methods**” section specifies the aspects specifically addressed in this paper.

² Translation by the authors.

³ In addition, an earlier collective study in the field of territorial ecology did focus on a typical touristic village of the Maurienne valley (Buclet et al. 2015) and this same valley is currently the focus of a cross-disciplinary project (<https://trajectories.univ-grenoble-alpes.fr/en/>).

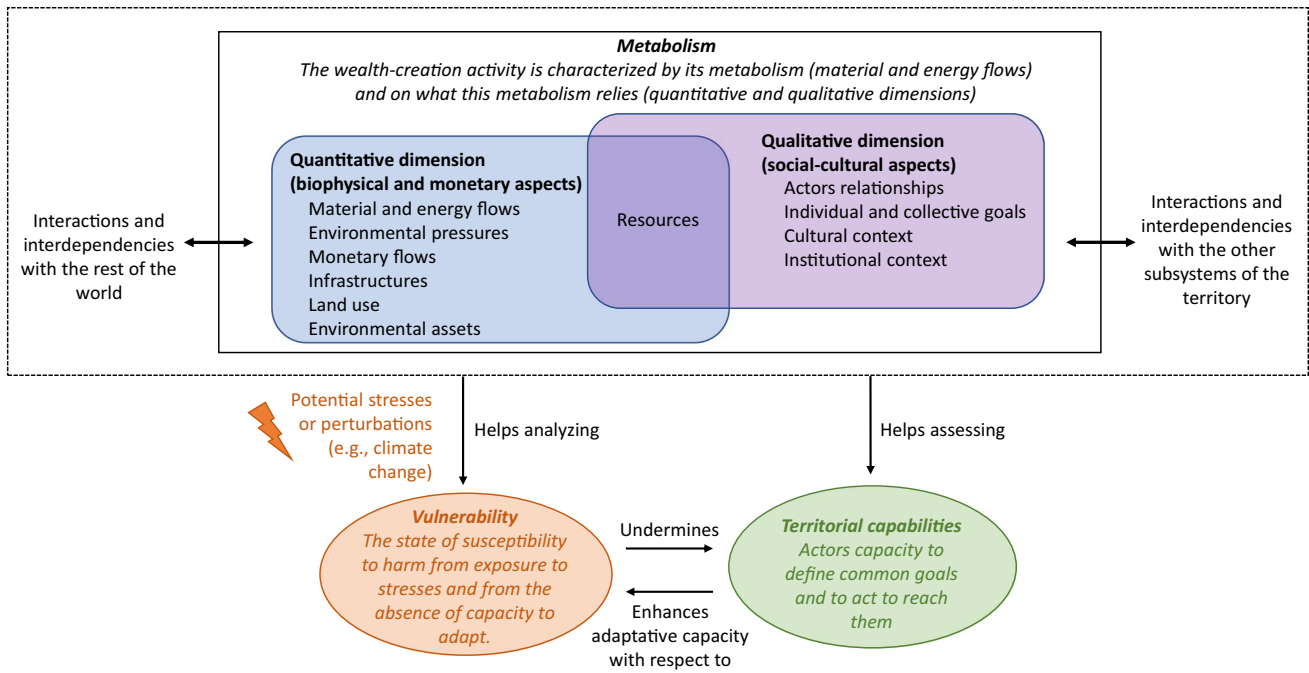


Fig. 1 Concepts used in the metabolism-capabilities-vulnerabilities (MCV) framework, and their relations. A wealth-creation activity (WCA) is described from the point of view of its qualitative and quantitative bases, including its relations with other territorial WCAs

and with the rest of the world. These material and social characteristics of WCAs are then used to analyze territorial capabilities and vulnerabilities, which are in dynamic interaction with one another

In the following subsections, WCA, territorial resources, and territorial capabilities are defined and discussed in turn.

Wealth creation activities and territorial resources

We rely on a framework describing a given *territoire* through its constituting wealth-creation activity subsystems (Buclet et al. 2015). This approach relates dominant metabolic functions (material flows and stocks) to structuring activities, from material and socio-economic points of view. This approach also aims at integrating immaterial resources to material ones. These immaterial resources include, e.g., know-how, cultural assets, reputation..., and, coupled to material and financial resources, produce a clearer picture of the stakes and dynamics involved in material flows, as well as the role of the (local or distant) stakeholders involved in the process. Further details can be found in section A2 of the [Electronic Supplementary Material \(ESM\)](#).

The MCV framework enables us to take into account the multi-dimensional aspects of the concept of resources. This is especially true of territorial resources (Gumuchian and Pecqueur 2007), a specificity at the crossroad of geography and economics. From an economic point of view, territorial resources induce unrecoverable transaction costs (Colletis and Pecqueur 1993), i.e., these resources cannot be used in other contexts. This follows because, for example, they relate to the feeling of belonging to a place (Colletis and Pecqueur

2005), to a landscape (Peyrache-Gadeau and Perron 2010), to heritage (Landel and S enil 2009), or to any other material or immaterial element valued for its local specificity. Territorial resources can be material or immaterial. Understanding material flows relies in an important way on the recognition of the role played by these fundamentally immaterial resources. In particular, one needs to pay attention to the way they combine with material and financial resources, usually more generic. This combination is at the root of wealth-creation in any local subsystem. It leads us to grasp the characteristics of a sub-system in a territorial way, rather than in a sectorial way, as many of these territorial resources are necessary to several wealth-creation activities (Buclet 2021). In this perspective, the dynamics of the *territoire* as a whole, with its specificities, explains many aspects of each activity and conversely the analysis of these activities highlights the networks characterizing the territorial dynamic.

Territorial capabilities

The study of territorial capabilities is based on the concept of capability (Sen 1999). As Kleine (2009) puts it, “*in Sen’s approach, ‘functionings’ are the various things a person may value doing or being, such as being adequately nourished, being healthy and being able to take part in the life of a community. [...] a person’s ‘capability’ refers to the*

alternative combinations of functionings that are feasible for her/him to achieve. The focus of development, thus, becomes increasing a person's capability set, or her/his substantive freedom, to lead the life she/he values."

In the present work, we make use of a similar concept is at the level of a *territoire*, rather than at the level of individuals, and refer to *territorial* functionings instead. This variant is referred to as territorial capabilities (Buclet and Donsimoni 2018), in order to focus on the potential of autonomy in deciding and acting at the territorial level. Beyond the capacity to anticipate and absorb disturbances or shocks of various sorts (Dauphiné and Provitolo 2007), the learning and innovation capacities of the *territoire* and its ability to improve on its own inner workings play a crucial role to reduce vulnerabilities (Buclet and Donsimoni 2018). The level of territorial autonomy of wealth-creation activities is an important piece of information to assess these capacities.

Hence, the notion of territorial capabilities refers to a form of collective capability (Evans 2002; Ibrahim 2006) existing in a specific *territoire*, depending on the local stakeholders' ability to make use of their resources and to engage in a collective dynamics, in particular through the *territoire* (formal or informal) institutions and networks. Such territorial capabilities condition the local possibility of mastering future trajectories and of anticipating disturbances or major changes, while taking into account the specific objectives of local stakeholders. Finally, territorial capabilities also depend on the ecological sustainability of wealth-creation activities, in their local and external dimensions.

Relatedly, strategies aimed at enhancing the specificity of local productions tend to improve the capabilities of local stakeholders, due to increased profit margins (Pecqueur 2001); this helps increasing local autonomy and maintaining local activities, in particular in mountain areas (Janin et al. 2015). In the case of productive supply chains, changes in individual capabilities may affect the capability structure of the whole production supply chain, and vice versa. These points contribute to the ability of the *territoire* to control its own evolution, and allow stakeholders to anticipate events while taking into account local objectives.

Comparison with other frameworks

Several features of the MCV framework can be emphasized in relationship to other works. The ones selected here share several key aspects with the MCV structure and aims (for more details, see Table A1, ESM, itself inspired by the work of Binder et al. 2013):

- It is compatible with other well-known frameworks in the fields of vulnerability, resilience, or sustainability, namely, Turner et al. (2003), Füssel (2007), and McGinnis and Ostrom (2014). Indeed, these frameworks pro-

vide grids of analysis but are not prescriptive in terms of methods to investigate each component.

- Contrary to social-metabolism studies (Haberl et al. 2016) which can be deployed at all scales, it specifically targets local scales because it investigates the roles, motivations, and constraints of individuals and groups involved in the territorial metabolism.
- It is knowledge-oriented rather than action-oriented, even though the goal is *in fine* to facilitate action by making actors reflect on these analyses.
- It does not produce any ecological assessment (on ecosystems exposure or sensitivity to climate change etc.), but can however mobilize pre-existing ecological knowledge to highlight consequences of stresses or perturbations on flow circulation.
- As in Binder (2007b) and Binder et al. (2004), it couples MFA with agent analysis describing the cultural, institutional and power-related factors enhancing or restricting options accessible to stakeholders. MCV however develops the notions of territorial capabilities and vulnerabilities.
- Many similarities also exist with Wilson et al. (2018), although these authors do not rely on a detailed analysis of the material functioning of the *territoire*.

Material and methods

Metabolism

Exploratory interviews and existing reports led us to reorganize the items of Fig. 1 for the purpose of our specific case study. Indeed, some items did not seem important to the understanding of the Beaufort WCA, and some could be grouped together, for instance, the institutional context is mentioned along with actors' relationships, and land use and environmental assets are mentioned in the MFA subsection. Little is said about infrastructures. The focus would be different for a different case study. The sources of qualitative and quantitative data used in our case study are detailed in Table B1 (ESM).

Actors relationships

Ten interviews and eight non-participant observations of various stakeholders' meetings allowed us to draw a map of the interactions between the main groups (Stein and Barron 2017). They also helped us to understand the organizational and institutional context of the Beaufort supply chain, as well as its stakeholders' motivations.

Material flow analysis

The interviews made it possible to identify existing reports providing data for the MFA (itself performed along the lines of Courtonne et al. 2015): fodder production, imports and consumption, water for irrigation, use of mineral fertilizers and pesticides, production, and sales of milk, cheese, and other products. Details are presented in ESM, section C1, along with the references used to estimate livestock excreta, grazed biomass, and water for animal watering.

Environmental pressures

The estimation of environmental pressures is performed by coupling material flows to Life Cycle Analysis (LCA) databases (ISO 2006). The method used is straightforward (Courtonne et al. 2016): we multiply a pressure intensity per unit mass (e.g., GHG emissions per liter of milk, from LCA) with a total volume or mass (e.g., total volume of milk produced per year).

We rely on the Agribalyse LCA database (Koch and Salou 2016). This LCA database is devoted to French agricultural products and distinguishes a number of production techniques (e.g., organic or conventional farming) in various types of landscapes (e.g., plains or mid-mountain ranges). The database did not consider the alpine type of agriculture and cattle farming, but did analyze a very similar one for the production of “mountain milk” in mid-mountain Massif Central (the mountain range occupying the center of France). We have used these data as a starting point, updating them whenever possible with relevant data directly collected in our study area (milk yield and fodder consumption). Three impact categories were then computed: Global warming potential (*ReCiPe Midpoint (H) V1.13, climate change, GWP100*), eutrophication potential (*CML 2001, eutrophication potential*) and acidification potential (*ReCiPe Midpoint (H) V1.13, terrestrial acidification, TAP100*).

Regarding water, we relied on existing reports and interviews to try to assess the extent of the pressure due to Beaufort production on local water resources.

Direct pressures are the ones generated by a process itself whereas indirect pressures are associated with process inputs. By definition, direct pressures occur on the *territoire* (except, in our case, for direct pressures from heifers overwintered outside the *territoire*). Indirect pressures can occur inside or outside the *territoire*. We make the hypothesis that indirect emissions associated with the following flows occur outside the *territoire*: imported fodder and feed, electricity, equipment, and buildings. Conversely, we consider that the following flows generate intra-territorial pressures: local fodder and straw, heat, and water. This distinction is useful

to analyze not only local vulnerabilities but also vulnerability transfers.

Monetary flows

Monetary flows through the supply chain (Dahlström and Ekins 2006) are estimated in two steps. Flows associated with milk production are estimated based on farms’ loss and profit statements detailing the sources of income and areas of expenditures. In addition, we estimated income related to farmers’ multi-activity. Flows associated with cooperatives are based on their annual reports. In a few cases, economic flows are estimated by multiplying mass with unit prices. Whenever possible we used the same classification as in the mass diagram. Details are provided in section C3 of ESM.

Potential stresses or perturbations

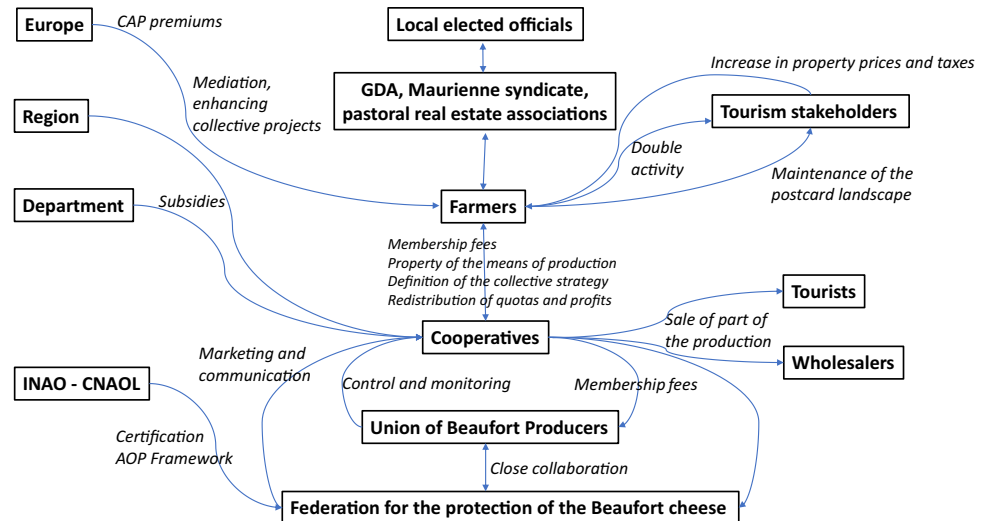
For this study, we decided to focus on internal (i.e., not exogenous) stresses or perturbations and on external stresses or perturbations that would specifically affect the WCA. For instance, we analyzed the potential impact of climate change through a literature review, because it is expected to have specific impacts on mountain agriculture, but we did not analyze the consequences of generalized economic shortages, as these would lead to impacts in all sectors of the economy.

Territorial capabilities

As defined above, this concept corresponds to the capacity of local actors to decide collectively the future of their *territoire* and to agree on the means to accomplish it, ensuring the sustainability of territorial activities. In this perspective, the authors analyze the following:

- The capacity of the actors of WCAs to control the decisions impacting their activity,
- The economic performance of WCAs and the capacity to seize territorial opportunities to generate more income,
- The environmental viability of WCAs and environmental pressures occurring on resources available to actors,
- The capacity of local actors to become aware of issues threatening WCAs and to engage in strategies to address them (such strategies can consist in reducing exposure, sensitivity and/or enhancing coping and adaptive capacities),
- The positive/neutral/negative effects of the studied WCA on the other WCAs of the *territoire* (and vice-versa) and their impact in terms of capabilities strengthening or weakening.

Fig. 2 Stakeholders' network diagram, in relation to Beaufort production. NB: a "département" is a French administrative and territorial subdivision, associated with one or more local urban poles of attraction, and of typical extent of a few tens to a hundred kilometers



This analysis is performed on the Beaufort cheese WCA, both for its importance for the present case study and for illustration purposes.

Vulnerabilities

The identification of structural flows and structural elements of the Beaufort WCA follows from the territorial metabolism and its qualitative and quantitative dimensions (Fig. 1). These are considered either because one deals with high volume, and/or non-substitutable flows (e.g., certain production inputs), and/or impact-intensive flows, and because actors play a key role in these circulations.

The weaknesses of these structural flows/elements can be questioned: what exogenous events or conditions could harm them and to what extent? Interviews conducted with actors and a literature review provide elements of answer to this question, but this vulnerability analysis is by no means exhaustive. In particular, the authors attach more importance to understanding structural elements than to listing every possible source of perturbation that could harm them. Finally, as shown on Fig. 1, one has to analyze the interactions between capabilities and vulnerabilities. For instance, it is reasonable to expect that the actors' awareness of their vulnerabilities increases their capabilities and adaptive capacities, which in turn can reduce the overall vulnerability level.

Results from the Beaufort case study and discussion

The metabolism of the production chain in the Maurienne valley

Actors relationships

In order to understand better the interplay between metabolism quantitative analyses and stakeholders' capabilities, it is useful to first present a general picture of the various stakeholders types and relations in the context of the Beaufort cheese WCA. These are shown on Fig. 2.

Beaufort production was certified as a Protected Designation of Origin (PDO) in 1968. This label guarantees both the origin of the product and the quality of the production process, and is at the basis of the valorization of the Beaufort cheese as a territorial resource (Janin et al. 2015). The technical requirements for the PDO label concern cows' breeds (only two local alpine breeds are authorized), cows' nutrition (mainly based on fodder and grass, of which 75% at least must be locally produced), milk production (limited at 5000 kg/cow/year), and a strict adherence to traditional practices of milk processing and transformation (INAO 2010).

Our interviews and observations allowed us to draw a clear picture of the Beaufort actors' network. Beaufort production in the Maurienne valley is structured around three cooperatives, each one collecting milk and making Beaufort cheese in its geographical sector. Furthermore, they supervise together milk

by-products (whey and cream) and partake in the economic development of these by-products in a common production unit. Milk producers directly manage the Maurienne valley Beaufort cooperatives through an elected bureau and administrative council; they take part in the decision-making process of the cooperatives and in strategic choices. Representatives from each cooperative constitute the Federation for the protection of the Beaufort cheese; this structure defines production quotas for each cooperative (in order to adjust supply to demand) and is in charge of the commercial promotion of this production. The Union of Beaufort Producers ensures the conformity of the production to the technical requirements of the PDO label and performs inspections to this effect. It also offers optional technical advice to producers and cooperatives. The valley cooperatives have created dedicated structures for cheese direct sales and are in charge of negotiations with wholesalers. The Beaufort cheese is renowned, and the cooperatives have some edge in these negotiations.

Producers benefit from various subsidies, the largest share coming from the common agricultural policy of the European Union (Rivier 2019). Producers are also members of the two Groupements de Développement Agricole⁴ of the Maurienne valley.

Agriculture and tourism strongly interact in the valley (Buclet et al. 2015). Producers commonly have a seasonal job in ski resorts, and this constitutes a substantial source of income, contributing to the viability of the farming activity (Clavel 2014; Schoch 2014a, 2014b). Furthermore, cooperatives' managers emphasized that (i) sales to tourists represent a dominant fraction of all sale shares, through direct sales or wholesalers, and (ii) cattle farming in alpine pastures maintains the characteristic scenic mountainous landscapes of the alpine region, a major asset for tourism.

Finally, according to our interviews and non-participant observations, local stakeholders share a strong attachment to their way of life and aim at preserving farming in the valley.

Material flow analysis

MFA reveals that the supply chain is dependent on external resources (imported fodder, imported concentrated feeds, heifers overwintered outside the territoire), but that this dependence is limited. For instance, in addition to local grazing, nearly 80% of the fodder is grown locally (see Fig. C1a in ESM). Fodder land and summer and high altitude pasture

land (estive) are therefore an environmental asset of the Beaufort cheese WCA.

Water flows are predominant, quantitatively speaking, and roughly equally divided between irrigation and livestock watering. One may therefore wish to evaluate the possible stress on local water resources exerted by this WCA, be it quantitatively through direct water use, or qualitatively through eutrophication due to fertilizer use. On this last point, our estimation confirmed that mineral fertilization was very limited with a contribution of less than 20% of total nitrogen inputs of the activity (see section C1, ESM), which in itself is a fraction of organic standards (see next subsection). The other issues related to water use are addressed right below in the next subsection.

In addition to the diagram in real mass (C1a in ESM), a diagram in fat mass is drawn (C1b in ESM). Comparing the MFA in fat mass and monetary flows ("Monetary Flows" section) shows that fat mass is a good proxy for economic value.

Environmental pressures

Direct GHG emissions associated to Beaufort production amount to ~10 kt CO₂ eq/year (see table C2b in ESM). They represent one fourth of direct emissions of agriculture in the Maurienne valley (40 kt/year, ORCAE, 2020). In comparison, industrial activities in the valley generate about 580 kt and transport about 110 kt/year (ORCAE), underlining the importance of industrial activities in the territoire and the small relative responsibility of local agriculture regarding climate issues. To put these results into perspective, at the national level, agriculture represents 19% of total GHG emissions (Ministère de la transition écologique 2021). Furthermore, Table C2b (ESM) contains a comparison between milk production in the Maurienne valley system and the French average. This indicates that, overall and unlike other cattle-based systems in France, the Beaufort supply chain will most likely be little affected by emission reduction strategies, even if the impact per kg of milk is about 30% larger than the French average (because of a lower productivity). Indeed, total emissions remain small because the system is very extensive per ha (66% lower than the French average), while creating economic and environmental value (maintenance of landscape and, indirectly, carbon sequestration, although not quantified here).

Turning to the eutrophication potential affecting local watersheds, the authors computed the nitrogen input on fodder-land through the spreading of manure and found a total of 42 kg N/ha/year. Mineral fertilization amounts to about 8.5 kg/ha/year (see section C1, ESM). The total of 50.5 kg/ha/year is very low compared for instance, to the standards of organic farming (170 kg N/ha/year). Thus, in general, the supply chain does not seem to be a burden for water quality, but this may be the case in some specific areas. For instance, according to the water agency (Syndicat du

⁴ Groupements de Développement Agricole (GDA) are farmers' associations dedicated to mediation between agricultural activities and local jurisdictions; they center on local farming issues and foster collective projects in the Maurienne valley.

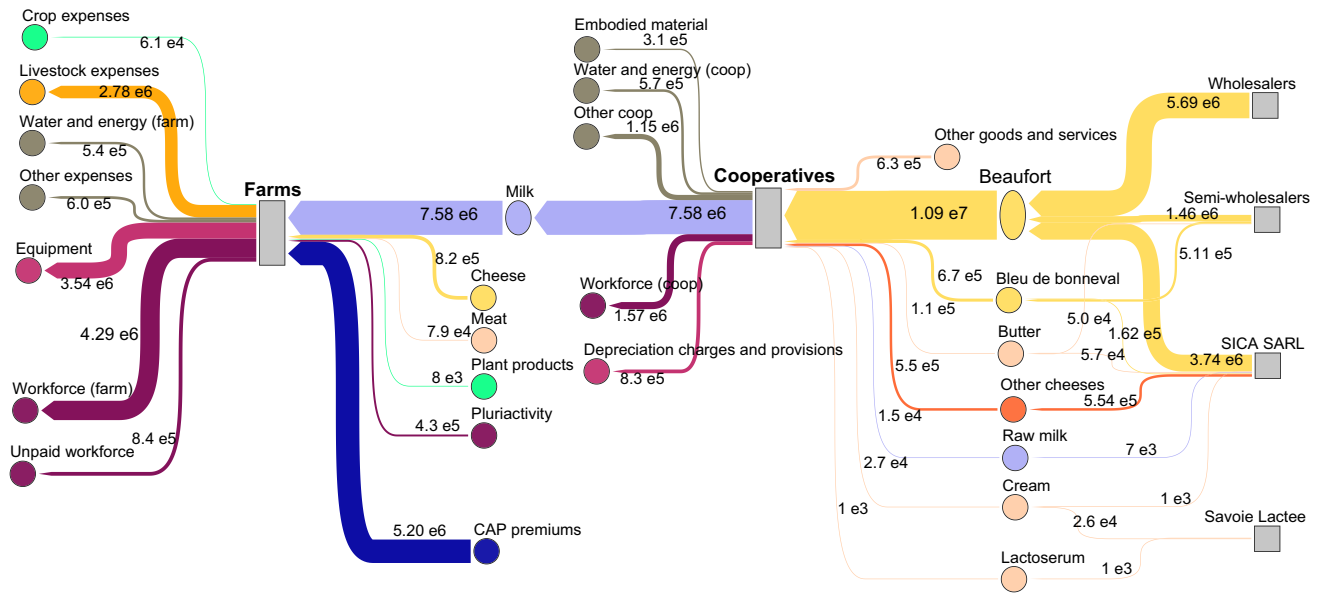


Fig. 3 Economic flows for Beaufort cheese production in the Maurienne valley, in euros (€). Note that monetary flows are opposite to the material flows of Fig. C1a (see ESM). We use the scientific nota-

tion, e.g., $4.2 \text{ e}3 = 4.2 \times 10^3 = 4200$. Color code: yellow and dark orange = cheese; blue = raw milk; orange = other milk products; dark purple = workforce salaries; dark blue = subsidies

Pays de Maurienne 2020), about 25% of water bodies in the Arc river watershed, which corresponds to the study area, have their physico-chemical state degraded by ammonium, phosphorus, or phosphates. A more detailed analysis would be necessary to determine if this is related to Beaufort production.

Regarding water quantitative balance, there is no indication that current water withdrawals occurring on the territoire threaten waterbodies: to our knowledge, no planning document exists to deal with such a problem (e.g., no study of withdrawable volumes, no zone of water allocation), meaning at least that the watershed was not considered a priority by the water agency for Rhône-Méditerranée-Corse. This does not necessarily mean that tensions on water use do not exist in some specific areas but the subject was not cited as an important issue during our interviews. For the Beaufort milk production in the valley, only a few tens of hectares of meadows and pastures located in “Haute-Maurienne” (upstream) are irrigated (see ESM, section C1), although irrigation networks are in extension (see also the “Vulnerabilities” section).

Finally, it is interesting to quantify externalized pressures and to identify what they are associated to. Among total emissions, 17%, 26%, and 28% occur outside the territoire respectively for GHG, eutrophication and acidification potentials. Hence, pressure externalization to other territories exists but is limited. It is mostly due to imports of concentrated feed.

Monetary flows

Four salient features can be drawn from the economic Sankey diagram shown in Fig. 3:

- Direct sales represent 28% of Beaufort mass but 34% of Beaufort income, confirming that the profit margin is higher in the absence of intermediates. One kilogram of Beaufort generates one third more income for the cooperative when sold directly.
- The direct involvement of farmers in cooperative management results in an efficient redistribution of income from cheese sales to the farm level, leading to a higher milk price with respect to the national average (RICA).
- This type of production is highly dependent on subsidies from the European Union agricultural policy — a generic feature of farming in France (RICA). Subsidies are quite important for cattle farming in open pastures⁵ in general and in mountain areas in particular.
- Income originating from winter jobs in ski stations may seem low compared to other flows but is in fact non-negligible if compared to the net income of farmers: the authors estimated that nearly 20% of multi-active farmers’ income originates from winter jobs and about half of the farmers are multi-active (see ESM section C4 for estimation hypotheses).

In order to put these features into perspective, it is useful to keep the two following points in mind:

⁵ 50% for grazing livestock compared for instance with 32% for dairies (Matthews 2019).

- In the Maurienne valley, about 90% of all collected milk is used for Beaufort cheese production (Chambre d'Agriculture de Savoie-Mont Blanc 2011). This is much more than the national average, where about 10% of the milk production only is assigned to the making of PDO certified cheese. On average, the price of PDO cheese (more accurately the revenue per kg of cheese) is about 75% higher than non-PDO cheese (calculation by the authors based on CNAOL and Agreste data).
- In the Maurienne valley, one finds about 10 cows for 30 ha of pastures. The average production is ~3850 L/cow/year. The national average is about 60 cows for about 70 ha of pasture for a production of ~6630 L/cow/year (Centre national interprofessionnel de l'économie laitière, 2020). The lower production rate is due to the higher elevation and to the breeds of cows used for Beaufort production as well as to the PDO restrictions in their nutrition. However, this difference has little or no impact on farm income (comparison between RICA and Cerfrance data).

A potential stressor: climate change

According to Gobiet et al. (2014): “From the late nineteenth century to the end of the twentieth century, Alpine temperatures have risen at a rate about twice as large as the northern-hemisphere average, amounting to a total annual mean temperature increase of about 2 °C.” In the future, climate change is expected to be especially strong in the Alps (Calanca, 2007), impacting in particular the seasonal cycle of precipitation (less rainfall in the summer and more in winter) and temperature and precipitation extremes. Snow cover is expected to decrease drastically below 1500–2000 m (Gobiet et al., 2014). These changes will affect summer mountain pastures in both the short and long term with high interannual variability in the forage supply (Deléglise et al., 2015; 2019).

According to GIDA Haute-Maurienne (2016), the Haute-Maurienne area has already experienced successive droughts since 2003, leading to deficits in soil moisture, which constitutes according to them “the only serious limiting factor for fodder and grass production.”

Hence, even if quantification remains difficult because of climate modeling uncertainties at local scales, an increased risk of consecutive bad production years does exist, with potentially severe consequences on the viability of a number of mountain farms. Furthermore, the likelihood of such events increases as climate change unfolds.

Territorial capabilities

The discussion presented here relies on the above analyses as well as selected material from stakeholders' interviews.

The main objective is to illustrate the criteria presented in the “Territorial capabilities” section.

The manager of one of the cooperatives emphasized that, thanks to the cooperative system, producers have a large say on their conditions of production and of sale of their products. This is an exception in French agriculture, rather than the rule. It is rooted in the specific Beaufort collective structure, which in turn enhances the sustainability of local agricultural practices (Lallau and Dumbi 2008).⁶ In this respect, Beaufort cheese producers have a better control over their own future than most farmers. Moreover, the balance of power is favorable to cooperatives regarding Beaufort sales as the demand for this reputed product is relatively important. Finally, according to Clavel 2014, Schoch 2014a, Schoch 2014b, and Schoch 2015, a large fraction of farmers obtains additional income with winter jobs in ski stations. This constitutes a significant form of territorial opportunities.

Environmental pressures do not constitute a serious issue. Pressure externalization is limited (since only 17 to 28% of studied pressures are externalized, see “Environmental pressures”) and mostly due to the external supply of concentrated feed.

Hydroelectricity production, primary industrial production, tourism, and agriculture are the most important wealth-creation activities in the Maurienne valley, the first playing an important role for the others (Buclet et al., 2015). These activities are all highly dependent on their local environment, making alpine valleys a prime example of socio-ecosystems in developed countries. Tourism benefits from agriculture thanks to the conservation of scenic open landscapes and from the image of quality products such as the Beaufort cheese. In turn, the Beaufort WCA benefits from winter tourism regarding winter jobs (see above) and regarding direct Beaufort sales, about three quarters of which occur during the winter or summer tourist season, according to our interviews with the three cooperatives.

Vulnerabilities

Based on the “Vulnerabilities” and “The metabolism of the production chain in the Maurienne valley” sections, the following structural/flow elements are considered with respect to the vulnerability analysis performed here:

1. farmers (workforce) are structural elements of the WCA;

⁶ Conversely, for “captive supply-chain production” (Ballet et al. 2008), producers are highly dependent on wholesalers whose leverage in negotiation is substantially stronger. Wholesalers can influence or even manipulate the supply-chain functioning and this represents a risk for producers' capabilities (Randrianasolo and Randrianasolo 2008).

2. the current economic model of farmers relies a lot on subsidies (about half the annual revenue, Rivier 2019),
3. the PDO requires a large fraction of local fodder as winter feed; this fodder is produced on fields that are submitted to real estate pressure and depend on current climate conditions.

These structural flows/elements may be undermined in a number of ways:

- (i) The farmers' average age is rather high (45 years, Clavel 2014; Schoch 2014a, 2014b) and this population keeps aging, a common problem for agriculture throughout France (Centre national interprofessionnel de l'économie laitière 2020). According to the Chamber of Agriculture, farmers' retirement without takeover⁷ is expected to lead to a 14% reduction in milk production in the Maurienne valley within the next 10 years. This would lead to a reduction of income on the remaining farms due to shared fixed charges, further weakening the viability of the whole production process (see Fig D1 in the ESM). The authors estimate that a 14% reduction in global milk production would lead to a 16% loss of income per farmer on average under the assumption of fixed Beaufort cheese price (but see point (ii) right next). The most vulnerable farms are expected to suffer even more from this abandonment.
- (ii) If EU subsidies were reduced or suppressed, Beaufort cheese would need to sell up to 40% higher to compensate for the induced economic loss (calculation of the authors based on Rivier 2019). This in turn could induce a lower demand for this type of cheese, a point partially mitigated by the fact that this type of cheese is bought by rather well off segments of the population. In any case, the loss of EU subsidies would affect the whole agri-food supply chain, making cheese price increase only relative.
- (iii) Climate change may modify the local rainfall regime and lead to a decrease in fodder yields, as pointed out earlier. Quite clearly, local stakeholders have little influence on climate change and its consequences. The issue rests on identifying adaptation capacities, and some preventive action are required on this front. Deep changes in PDO requirements for Beaufort seem

possible but unlikely. Some producers asked for a less constraining limit on local fodder, but INAO threatened to remove the PDO label of Beaufort cheese if this were the case. Producers will therefore be faced with either a reduction of their production — with potential detrimental consequences for the viability of the activity — or a compensation for the lower yields of alpine pastures and hay meadows through an increase of farmed areas wherever possible (Perrin 2012). On top on this, farmers are constrained by the real estate pressure due to tourism on fodder land (Schoch 2011). The restoration or extension of existing irrigation networks in the Haute-Maurienne area is however already encouraged by relevant authorities, the objective being to ensure a minimum water allotment to high potential plots (non-participant observation during a general meeting of a GDA 2018).

Vulnerabilities follow also from potential snowball effects and feedbacks loops. Climate change could potentially reduce snow cover in winter, and reduce local fodder production. If winter tourism cannot adapt and declines, this could translate in less income for some farmers who hold winter jobs in ski stations as well as in a decrease in direct Beaufort sales, half of which occur in winter. This will make farms more economically fragile and less capable to adapt to the constraint of lower fodder production. If a fraction of farms ceases its activity, negative consequences for the whole WCA described above ensue.

Interactions between capabilities and vulnerabilities

Territorial capabilities rely on social, economic, and bio-physical assets and could be undermined by any of the above sources of vulnerability. A possibly less obvious point is that vulnerabilities, if not addressed, could in the long run affect the representation actors have of the WCA. A reduced trust could trigger a domino effect, reducing in turn territorial capabilities.

According to an observation made during the 2017 general assembly of the *Federation for the protection of Beaufort cheese*, it seems that a few farmers under-valued the benefits of the cooperative system, because of its constraints, such as milk production quotas. Instead, they may consider selling their milk production to large milk companies in the future. This is potentially damaging, as cooperatives constitute the most powerful tool enhancing territorial capabilities (see "Territorial capabilities").

⁷ The hypothesis of a difficult transmission of the farms is justified by aging equipment that is costly to upgrade and by hiring difficulties in this type of activity (already experienced today).

Local actors may become aware of vulnerability factors and engage in strategies to address them. Indeed, we have already outlined the important level of collective actions among Beaufort producers, through a panel of networks ensuring decent incomes, improvements in working conditions, and control on product quality and quantity. The main concern revolves around the possibility of maintaining these assets while facing upcoming changes — mostly climate change. The rules of INAO (the French national PDO institution) allow producers to import up to 50% of animal feeds (INAO 2017), a possibility not fully exploited yet. However, in terms of territorial capabilities, such a dependence on the outside would be a vulnerability in itself.

Another option briefly mentioned above and considered in more detail here is to increase mountain pasture areas. Various factors have led to their reduction in the twentieth century: difficulty of mechanized access, decrease of the population of farmers, reduced availability of hired work force.... Recent public policies in Switzerland (2014–2017) have slowed down this tendency through specific subsidies (Société d'Economie Alpestre de la Haute Savoie 2019). Such collective actions supported by public policies are probably the best way to fight agricultural abandonment or even increase the surfaces devoted to mountain pastures. Furthermore, mountain pasture landscapes have value beyond cheese production and this may provide a useful asset in collective discussions, in conjunction with concerns about large-scale reforestation of pasture areas (a factor reducing landscape beauty and attraction for tourism) and the protection of biodiversity. This relates to NCP approaches (Nature Contribution to People, Diaz et al. 2018).⁸ Integrated management plans (*plans de gestion intégrée* or PGI), in relation with local pastoral real estate associations, aim at a better coordination of all involved actors for the promotion of mixed forest/pasture units in mountain areas (Société d'Economie Alpestre de la Haute Savoie 2019).

The value of local resources may therefore increase territorial capabilities through summer tourism, seen as a potential way to balance the future loss of winter tourism. This may enable a socio-ecological transition, by promoting forms of tourism more adapted to global change. This also constitutes an argument for changing the basis of attribution of EU agricultural policy subsidies, but negotiations in this direction have not yet been successful.

These various leads are typical of collective actions, in line with our definition of territorial capabilities — i.e., a geographically anchored collective capability. The most important asset in this respect resides in production cooperatives and their network of connections with one another and with the various local organizations in charge of the

promotion of the cheese production activity. These include the Federation of protection of the Beaufort cheese, the Union of Beaufort Producers, local pastoral real estate associations, and the Maurienne Syndicate (an institution in charge of a coherent territorial project for the whole valley). The territorial specificity of this form of collective capability follows from the rooting of these structures in local resources and practices but also, as pointed out, from the synergies between human activities and local ecological conditions.

Conclusion

In this article, the MCV framework (metabolism-capabilities-vulnerabilities) was introduced and applied to the case of the Beaufort cheese production in the Maurienne valley, in the French Alps.

Our territorial metabolism analysis, focused on wealth-creation activities (cheese production for the most part), allowed us to relate purely material and environmental stakes to socio-economic ones. In other words, this enabled us to look at the *territoire* as an actual socio-ecosystem. We recall here the definition of a *territoire* as a network of stakeholders' interactions anchored in a specific area, constituting a shared living space. Attributing capabilities to the *territoire* itself gives it the status of an actor in constant interaction with its environment. In this way, we were able to pinpoint a number of territorial capabilities. Our aims were not to identify these capabilities in a systematic way but to point out their systemic articulations, such as the contribution of farming to tourism through the co-production of landscape, which in turn supports Beaufort cheese sales, as tourists buy about half of the production. In particular, with respect to vulnerabilities potentially produced by climate change, the authors argued that collective capabilities are mutually reinforcing and rooted in collective actions.

From an empirical point of view, several points must be emphasized. While the Beaufort context is common to other mountain areas, the conclusions drawn in this work cannot be replicated without further investigation. Pre-existing information was abundant for the Maurienne valley cheese production activity, and reproducing the present study on other territories would be more time-consuming, or even incomplete if some information remains confidential (e.g., monetary flows). One could imagine instead to conduct the study in a more participative way following Sharifi (2016) who argued that stakeholders' implication is an important part of the learning process. Regarding environmental pressures, it would be interesting to assess the level of carbon sequestration provided by the Beaufort cheese WCA (wealth-creation activity) to compare it with greenhouse gas emissions; similarly, a more precise knowledge on water

⁸ See in particular Grosinger et al. in this special issue.

qualitative and quantitative issues in the *territoire* would be useful. Finally, similar analyses should be conducted on the other structuring activities of the Maurienne valley.

From a conceptual point of view, this work is an attempt to contribute to vulnerability and territorial metabolism/ecology studies. The authors believe that approaching vulnerability through the lens of a WCA's metabolism is promising. First, analyzing territorial economies in subsystems (WCA) is a way to overcome their complexity while retaining their interactions. Second, the framework helps focusing on the relations between the WCA material basis, the network of actors involved, and the social-economic-cultural context.

Further research would help to design more precise criteria in order to identify and classify the structural elements of a WCA, and to study the possible territorial strategies to address vulnerabilities and their relations to territorial capabilities. A deeper analysis of the power relations between actors would be helpful for this purpose. Some of the frameworks discussed in Section A1 (ESM) may be used to this effect.

Although our study was conducted before the COVID-19 pandemic, this unexpected and continuing crisis confirms the interest of such analyses. Indeed, this crisis has seriously damaged the winter tourist season, with (focusing on the present work) foreseeable consequences on many interconnected mountain activities.

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