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Research article

Towards a new framework to assess agri-food value chains' sustainability – The case of chestnut value chain

Tarek Allali [a,*], Manola Colabianchi [a], Michele Moretti [a,b], Gianluca Brunori [a]

[a] Department of Agriculture, Food and Environment, University of Pisa, Via Del Borghetto, 80, Pisa, Italy
[b] Department of Engineering Management, University of Antwerp, Prinsstraat 13, Antwerp, Belgium

A R T I C L E I N F O

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A B S T R A C T

Food systems rely on natural resources for production causing their depletion. Sustainability assessment can encourage farms and agri-food companies to improve sustainability performances. Sustainability assessment frameworks and tools differ in their purposes, scope, methods of application, and required time for execution; however, most of them do not fit with value chains, or they do not cover all sustainability dimensions. Our objective is to propose a holistic framework to assess sustainability at agri-food value chains level. The proposed framework combines the Sustainability Assessment of Food and Agriculture systems (SAFA) (El Hage, 2012) [1] and The Agri-food Evaluation Framework (TEEB) [2]. It incorporates the concepts of Socio-Ecological Systems, Assemblage, and Social Practices. It integrates system dynamics by emphasising human and natural capital stocks and their users. We explain in detail the methodological steps we followed to construct and to apply this new framework to two case studies in Italy and France. The new framework was applied to real-life case studies and has shown its effectiveness and demonstrates its potential for widespread use in similar scenarios.

1. Introduction

Natural resources [1] are largely exploited due to global production, sometimes more than what ecosystems regenerate [2]. In a more specific context, Misselhorn et al. [3] and Prosperi et al. [4] assume that food systems contribute to natural resources' loss since they rely mostly on these resources for production. Thus, immediate solutions and developing processes for sustainability integration have become an urgent need [5–7].

Among the suggested solutions to achieve the Sustainable Development Goals, there is the upgrading of sustainable agri-food value chains (VCs) [8]. Developing agri-food VCs sustainably and improving their performances would offer important pathways out of poverty and benefit millions of poor people all over the world [9,10]. To follow-up the progress of a development operation we opt for an assessment exercise, where an assessment is defined as: "*a process we use to: (i) identify the gaps between current results and desired ones; (ii) place these gaps in priority order; and (iii) select the most important ones to be addressed*" [11]. Additionally, it is proclaimed that sustainability assessment is led to support decision making [11,12].

To date and for the last two decades, several frameworks and tools have been introduced to assess sustainability, they differ in terms of their scope, procedure, data resources and data collection methods, actors involved and the degree of their involvement, and sometimes the cost and time required for execution [13–15]. Scholars agree that there is no general framework or tool for sustainability

* Corresponding author.
E-mail address: tarek.allali@phd.unipi.it (T. Allali).

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assessment that fits all specific cases and contexts (i.e., IDEA[a], MOTIFS[b], RISE[c], COSA[d], etc.) [16–20]. As a response to this matter, de Olde et al. [15] suggested to develop tools and frameworks using different methods of measurement and indicators' selection for all sustainability dimensions. Qorri et al. [21] and Seuring and Gold [22] argue that sustainability assessment shall be considered further than a single company, because an effect (positive or negative) occurs along all stages of a product's lifecycle.

Approaches like Life Cycle Assessment (LCA) (including its case-specific modifications), Multi-Criteria Analysis (Fuzzy logic, Analytical Hierarchy Process AHP, Data Envelopment Analysis DEA, Hybrid Fuzzy-AHP-DEA) have been used to assess sustainability at VCs level [19,23]. However, complexity, time consumption, cost, and data availability prevent a large adoption of these approaches [24].

Acknowledging the abovementioned difficulties and drawbacks, the objective of this paper is to propose a novel holistic framework to assess agri-food VC's sustainability, that is simple and user-friendly. The proposed framework covers four sustainability dimensions (triple-bottom line (3BL), and governance) and adopts a social science perspective to analyse value chains configurations and their contribution to sustainability. Although, many research papers grouped sustainability assessment frameworks into categories [14,25,26], we aimed to build a framework that could be applied in different sectors, by keeping the general pattern with a certain flexibility to accommodate the needs of the specific case (e.g., list of included indicators). Accordingly, we would like to answer the following questions: (i) How could we holistically assess the sustainability of agri-food VCs, and (ii) how could we identify the key sustainability challenges facing an agri-food VC and its territory?

Although most of assessment attempts focus more on environmental sustainability on the account of other dimensions [23,27], the proposed framework considers the three known dimensions of sustainability (3BL). Additionally, this framework consolidates the concepts of social practices [28,29], assemblage [30,31], and socio-ecological systems [32,33]. Moreover, it extends the concept of "value" to non-market goods and services and assess how value is generated and distributed among the components of the socio-ecological system. The socio-ecological system analysis provides knowledge on the natural, human, and institutional factors - as well as their interactions – affecting VCs structural and dynamic configurations.

Moreover, the emphasis on human and natural capitals stocks aims to integrate system dynamics thinking, which goes in line with the recommendations of Rich et al. [34] and Muflikh et al. [35], which suggest that understanding stakeholders' beliefs and mental models would foster the transition towards sustainable agri-food VCs. For our framework's primary purposes, we intend to adopt a participatory approach targeting different VC's actors (producers, transformers, distributers, etc.), and advisors (i.e., extension agents), experts, and organisations (i.e., farmers' associations, cooperatives, or syndicates).

The framework has been applied to two case studies of chestnut VCs in Tuscany (Central Italy), and Ardèche (Southern France). Moreover, contrasting the application of the framework to these VCs allows to compare the outcomes of the two exercises, especially at territorial capitals level and the practices conducted to use these capitals that may differ.

The next section of this paper gives a brief overview of the concepts we adopted to build the new framework and guidelines of its application. The third section presents the findings of the research demonstrating the outcomes of the application of the framework, focusing on interpreting these results. Finally, the study concludes with a final statement, limitations, and recommendations for improvement.

2. Methodology

To date, numerous frameworks and tools have been developed and implemented for assessing sustainability of different agricultural systems and their components (i.e., IDEA, MOTIFS, RISE, SAFE[e], COSA, etc) [16–20]. However, recent studies have highlighted several shortcomings, including complexity of use, limited scope, and inadequate consideration of systems dynamics [35]. To overcome these limitations, we propose a composite framework that incorporates concepts from human–nature interactions theory. The next part of this section describes the importance of every component and its contribution to the construction of the framework.

2.1. Components of the new framework

2.1.1. TEEB agri-food framework

According to The Economics of Ecosystems and Biodiversity (TEEB) Agrifood initiative [1], the evaluation framework is conceived to provide a clear evaluation of agri-food systems and their related ecosystems. Additionally, it aims to emphasise the importance of different types of territorial capitals and how dependent are agri-food systems to the latter. It adopts a systemic approach to achieve real sustainability and efficient solutions to the challenges facing by agri-food systems, linking agricultural activities to the hosting ecosystem [36]. According to Patton [37], the TEEB Agri-Food evaluation framework focuses on a holistic appraisal of agri-food systems, considering the VCs established within the analysed systems.

[a] Indicateurs de Durabilité des Exploitations Agricoles or Farm Sustainability Indicators.
[b] MOnitoring Tool for Integrated Farm Sustainability.
[c] Response-Inducing Sustainability Evaluation.
[d] Committee on Sustainability Assessment.
[e] Sustainability Assessment of Farming and the Environment.

2.1.2. SAFA framework

The Sustainability Assessment of Food and Agriculture systems (SAFA) is conceived as a universal reference framework to assess all sustainability dimensions of agriculture and food systems, including forestry, livestock, cropping, fishery, postharvest, etc [38]. SAFA has been widely used, for example on aquaculture VC in Bangladesh [39], to assess the agricultural system in Latin America (Paraguay) [40], and of organic farming in Sub-Saharan Africa [41], demonstrating a high adaptability to different contexts and ability to be used with other tools and frameworks. Moreover, it fosters ongoing progress that can be achieved through diverse ways, tailored to specific context and users' capabilities. Most importantly, SAFA does not serve as a substitute for other tools and frameworks, but rather to establish a shared sustainability language for agricultural and food systems (El Hage, 2012 p.2-6).

The SAFA guidelines comprise three equally important documents: (i) a guiding version of SAFA demonstrating the importance of the four dimensions included and their fitness for food and agriculture systems; (ii) the SAFA indicators' list and their application methods and measurements. This document contains over a hundred default indicators belonging to 21 themes and 58 sub-themes [42]; (iii) the SAFA-tool, a software that is used to elaborate the outcomes of the assessment process, it helps to report the results in graphical way through spider maps.

2.1.3. Assemblage of social practices

Social practices are actions-based routines characterized by material elements (objects, tools, infrastructures) and organised with a purpose on the base of available competences and expressing specific meanings (conventions, expectations, tastes) [29].

Deleuze and Guattari [30] used the concept of assemblage referring to the links between segments forming an assemblage: material segments (e.g., bodies, actions, etc.) and expressive segments (e.g., regulations, plans, etc.). Considering agri-food VCs, examples of material segments would be actors conducting the practices, raw or processed materials, while the expressive segments might be, in this case, the skills needed at each practice application and the organisational approach to conduct these practices. Analysing a VC as an assemblage would help to capture the dynamic of the system in a way to cover the actors' engagements through different VCs simultaneously, instead of analysing their practices in a static manner within the frame of the one analysed VC.

The assemblage analysis will follow the approach proposed by Murray Li [43], which aims at recognizing alignments of different actors' objectives, providing emphasis to knowledge, and determine improvement and potential positive change in the assemblage.

2.1.4. Socio-ecological systems

Ostrom [32] defines a Socio-Ecological System (SES) as distinguishable subsystems, namely (i) Resource System, (ii) Resource Units, (iii) Users, and (iv) Governance Systems. These subsystems could be projected for example to (i) mountain area, (ii) timber forest, (iii) actors (involved in the exploitation of this forest), and (iv) rules and norms regulating the timber exploitation, respectively. In addition to this multitier hierarchy (that could be expanded when needed), the SES is considered a holistic for analysing different aspects of the system (social, ecological, policy, etc.) and at different levels (internal and external), emphasising their interactions and outcomes [44]. highlighted that the SES framework provides a common language that facilitates comparison between cases (which will be a crucial characteristic for our study). Food systems could be considered as complex SES, with different actors conducting various practices in different locations, which would make the sustainability assessment process of such a system a complex matter. To overcome this complexity, adopting the SES approach allows to better understand the interactions among the different components of the system in which the VC takes place, helping the identification of trade-offs and/or synergies between social and ecological outcomes [45,46]. The SES concept is based on intertwining nature and people [47], therefore, it fits well with the raising interest to multidisciplinary scientific frameworks, for their ability to capture the complexity of global challenges [48]. Moreover, SES research is substantially problem-oriented, with an emphasis on sustainability practices and policy communication [49]. Finally, the SES framework has a certain flexibility and it is able to undergo some modifications to fit with food systems. Marshall [46] and del Mar Delgado-Serrano and Ramos [50], provided examples of the application of modified versions of the SES. The former incorporated two additional first-tier variables to the original ones suggested by Ref. [33] (i.e., transformation system, and products). Where the latter set a third-level variables to improve the understanding and analysis of the SES. These new versions of the SES framework illustrated its capacity to afford more explanations and understanding of the studied system and its ability to achieve new outcomes that the authors reported as useful for both researchers and local communities. This characteristic of the SES is particularly important to our study, since we intend to co-produce some knowledge involving professionals and academics.

Finally, Table 1 summarises the different components of our new framework.

2.2. The new sustainability assessment framework

The proposed framework consists of two main components with the VC connecting these two assessment lines (Fig. 1). The Sustainability Assessment of Food and Agriculture systems framework (SAFA) [38] provides indicators to estimate the sustainably of

Table 1
Summary of the different component of the new framework.

SAFA	TEEB & SES	Assemblage & Social practices
A widely used assessment framework that perceived as a reference. It helped us with the indicators' selection.	They both helped us in studying the environment in which the VC's practices take place.	Analysing the VC as assemblage allowed us to detect the dynamics occurring along the VC, including its links with environment investigated through the TEEB analysis.

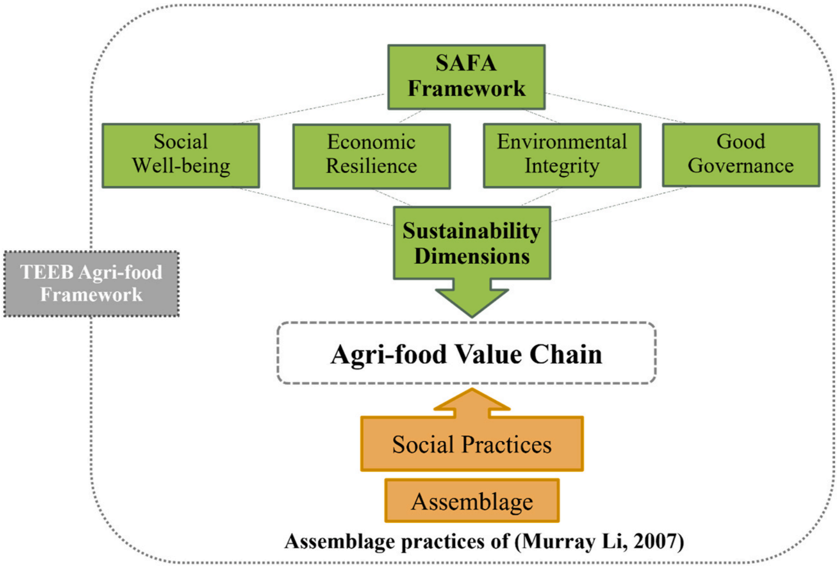

Fig. 1. The new framework to assess agri-food value chain's sustainability.

agri-food value chains accounting for the Economic Resilience, Environmental Integrity, Social Well-being, and Good Governance dimensions. While the "social practices" block, where the assemblage concept is applied, analyses the practices in which the VC's actors are engaged.

The abovementioned assessment paths, namely: SAFA indicators and assemblage analysis, will be applied in the light of The Economics of Ecosystems and Biodiversity framework (TEEB) [1] and the Social-Ecological Systems approach (SES) [32,33], where the first investigates changes in capital stocks, their flows, outcomes, and impacts on human well-being, and the latter characterises the connections between and within these capitals (or resource systems) and the users (people) of these resources.

As highlighted by Petit et al. [19] such multicriteria framework, incorporate multiple and diverse metrics, providing a more reliable and credible evaluation of sustainability as compared to mono-criteria frameworks. This is because multicriteria frameworks provide a more comprehensive and holistic assessment of sustainability and reduce the potential for biased outcomes and questionable decision-making.

Table 2 summarises the list of indicators selected to assess each sustainability dimension (descriptions and associated questions in Appendix). Table 3 contains the list of indicators (practices) linked to the best performance of an assemblage, every indicator is linked to at least one question asked to the same interviewees and attributed a score following a similar process as the sustainability dimensions process.

Table 2
List of selected indicators for each sustainability dimension.

Dimension	Indicator	Dimension	Indicator
Good Governance	Stakeholder engagement	**Economic Resilience**	Internal investment
	Engagement barriers		Community Investment
	Effective participation		Cost of production
	Conflict resolution		Price determination
Environment Integrity	GHG mitigation		Product diversification
	Air pollution		Stability of market
	Water conservation		Food quality
	Water pollution		Product labelling
	Soil improvement		Traceability system
	Land conservation		Certified production
	Ecosystem enhancing		Regional workforce
	Diversity		Local procurement
	Locally adapted varieties	**Social Well-being**	Wage level
	Material consumption		Gender Equality
	Energy saving		Support to Vulnerable People
	Energy consumption		Safety & health training
	Renewable energy		Safety of workplace
	Waste reduction		Indigenous knowledge
	Food loss		
	Hazardous pesticides		

Source [38]:

Table 3
List of indicators (practices) for the Assemblage Analysis.

	Indicator (practice)
Assemblage	Forging alignments Rendering technical Authorizing knowledge Managing failures and contradictions Anti-politics Reassembling

Source [43]:

2.3. Steps of application

2.3.1. Preliminary phase

Prior to start the evaluation process, the environment surrounding the analysed VC should be explored by identifying the key stakeholders involved at different stages, their different objectives and how these objectives are aligned, and their most relevant practices. This step would be the platform for the assemblage analysis. However, as suggested by Gasparatos [25] it is very important for identifying affected stakeholders' needs, values, and attitudes which are pivotal to conduct a successful sustainability evaluation.

On the other hand, applying the TEEB agri-food framework allows to analyse the SES in which our VC is taking place. At this step, the different types of capital stocks available in the SES, their flows, the expected changes occurred by the end of the VC are identified.

2.3.2. Indicators' selection

Indicators are critical elements of an assessment tool, they should meet certain requirements, for instance their relevance to the concerned system that will be assessed, clarity for users, measurability, and data availability [51,52]. Moreover, choosing the most suitable indicators is crucial for determining the evaluation outcomes [25]. In the same line, Mitchell et al. [53] and Hansen [54], found that adopting indicators to assess sustainability is helpful to deal with the assessed system's complexity and to help building decisions and actions to improve the analysed system. Moreover, the use of indicators helps to: (i) synthesis of data; (ii) giving an insight about the status quo of the system; (iii) show progress to reach certain objectives; and (iv) help users (decision makers) to underline new objectives and take appropriate decisions.

The SAFA list of indicators was the main source of indicators included in our framework. This list contains a very wide range of indicators, which are categorised as: (i) performance-based, (ii) practice-based, and (iii) target-based indicators [38].

Among the criteria to select indicators for our case - as we dealt with small enterprises - we knew that target-based indicators would not be that relevant, since small businesses usually do not predefine objectives to achieve in terms of environmental issues (e.g., targets for GHG emissions reduction, or water use preservation). Therefore, we included practice-based indicators for the Environment integrity dimension (e.g., GHG mitigation practices, soil improvement practices, etc). While for the other dimensions, both performance-based and practices-based indicators were selected.

As mentioned earlier, for the assemblage part we adopted a list of analytical questions defined according to six practices suggested by Murray Li [43] to analyse and keep functional an assemblage, namely: (i) forging alignments; (ii) rendering technical; (iii) authorizing knowledge; (iv) managing failures and contradictions; (v) anti-politics; and (vi) reassembling. Considering these practices to analyse an assemblage would help to improve its performance in terms of governance and outcomes.

2.3.3. Data collection

Data collection is conducted gathering secondary and primary qualitative and quantitative data through semi-structured interviews and published literature and datasets. Primary data were collected through semi-structured interviews with different actors (farmers, farmers associations' members, processors, distributors, citizen groups, public authorities, etc.) involved (directly or indirectly) in different stages of the VC. We opted to semi-structured interviews for the flexibility they provided when exploring interviewees' interests and visions. Additionally, they afforded us the possibility to steer the discussion with interviewees towards the elements deemed pertinent for our study.

In accordance with the ethical guidelines, including data management plan, data security, and personal data protection set forth by both: the Committee on Bioethics of the University of Pisa, and the MOVING HORIZON-2020 project grant n. 862739, under which this study was conducted. Moreover, an informed consent was diligently obtained from all interviewed participants.

2.3.4. Scores

Scoring indicators is an important and a sensitive step, especially because we need to express qualitative data in quantitative forms. Therefore, we assigned simple or multiple-choice questions to each indicator that participants (VC's actors) should answer and provide relevant information. In an iterative way, we attributed scores to these answers on a one to five Likert scale (1 unacceptable, and 5 best). For instance, the indicator "Effective participation" within the Good Governance dimension, we designed the following question: "Are there any decisions that were taken following stakeholders' suggestions?" And we provided these possible answers: always, never, or occasionally. The indicator in this case will be noted according to the interviewee's answer.

Four researchers involved in the study evaluated individually the answers given by interviewees following a process like the Delphi method, where each researcher attributed a score and gives a reason behind their choice. We repeated the operation for another round to reach a consensus on the final score for each indicator.

Our reference for a high performance is the objectives set by SAFA guidelines for each dimension. (i) for a Good Governance, all stakeholders shall be empowered and invited to share decision-making, there must be a certain transparency and public reporting, and there must be equal consideration of all dimensions while decision-making process. (ii) Environmental Integrity: there must be adoption of practices to mitigate climate change and practices to preserve the atmosphere, water, soil, and biodiversity. (iii) Economic resilience: presence of initiatives for investment and improvement, reinforcing smallholders' position in the market, and adoption of certifications and quality labels. (iv) Social well-being: gender equity and support for vulnerable people with special needs, preserving indigenous knowledge.

For what concerns the assemblage analysis, since it is meant to capture the dynamics of the system and to emphasise emergent properties of social entities by identifying the diversity of stakeholders involved, their interactions, their objectives, and investigate potential positive changes. A high score for this analysis means the system is well maintained, its stakeholders are diverse and express clear objectives. It means as well, that there is at least one requisite body to share knowledge and spread information.

2.3.5. Reporting

According to Ref. [55] sustainability assessment of food chains is a complicated process. Consequently, reporting the results of an evaluation operation is challenging. Communicating the outcomes of the assessment process to different VC's stakeholders (either included in the evaluation process or not) is very important. It would inform them of the current sustainability situation of their activity, it would stimulate reflection, and especially encourage thinking about improvement initiatives. Based on these outcomes, decisions for improvements and corrections will be taken, to establish a common platform for change and better management among all stakeholders. Therefore, a clear and well understood report is needed to be addressed to the targeted audience (farmers, processor, advisers, policymakers, etc). Radar chart figures and polygons were often used to show the evaluation results (e.g., MOTIFS and SAFA) [56].

2.4. Testing the new framework: the case study of chestnut VCs

We applied the new framework to two case studies. They concern chestnut VCs: one in Lucca, Tuscany Region (Central Italy) (Fig. 2a), and the second in Ardèche department, Auvergne-Rhône-Alpes Region (South-eastern France) (Fig. 2b). We chose chestnut VC as a case study because it possesses potentialities to promote mountain regions' sustainability and resilience; additionally, like many European regions, we could find chestnut groves in both sites, where it has a historic importance and a cultural value for locals. Moreover, chestnut groves deliver a large range of ecosystem services [57,58].

Chestnut tree is attracting research interest for its health benefits and organoleptic properties, for instance it is increasingly used by allergic people for its gluten-free flour and for its antioxidant activity [59].

Italy is the second largest chestnut producer in Europe after Spain with an annual production of 43 thousand tonnes [data] [60] [f], while although France is ranked 5th, we believe its case is interesting for the PDO label (Chestnut of Ardèche).

A total of 21 individual interviews were conducted (5 in Ardèche, and 16 in Lucca), and two workshops (in Lucca) were organised during the data collection, meeting with a variety of actors of both VCs (i.e., producers, processors, association and cooperative members, syndicate representative, chamber of agriculture, etc.). Additionally, we had the opportunity to attend to two multi-stakeholder's meetings (in Ardèche) to observe the governance pattern and decision-making process. The interviewees' sample was selected following a snowball sampling technique. We began by engaging with individuals within our existing network. Afterwards, these initial participants recommended additional key stakeholders, thereby expanding the scope and the diversity of our sample along our study's progress.

3. Results and discussions

The proposed framework has not been previously utilized. Additionally, there was no sustainability assessment studies of chestnut VCs to compare our outcomes with. Therefore, the following discussion will focus on interpreting the results of our study in the context of the new framework application.

As the initial objective of this study was to construct a new holistic framework and validate it, we applied it to two case studies of chestnut value chains in France and Italy. The application of the new framework to the two case studies, aimed at (i) assessing VCs sustainability, (ii) comparing them and understand the differences, and finally (iii) proposing suggestions to improve VCs' contributions to the sustainability of the respective SES.

3.1. VC analysis (TEEB framework) – Preliminary phase

Table 4 summarises the findings of our investigation concerning different territorial capitals used along the different stages of the two VCs, the practices conducted, the actors involved, the flows between the different stages, and finally the values created and the

[f] Database accessed on 26 April 2023. https://www.fao.org/faostat/en/#data/QCL. Last update 23 March 2023.

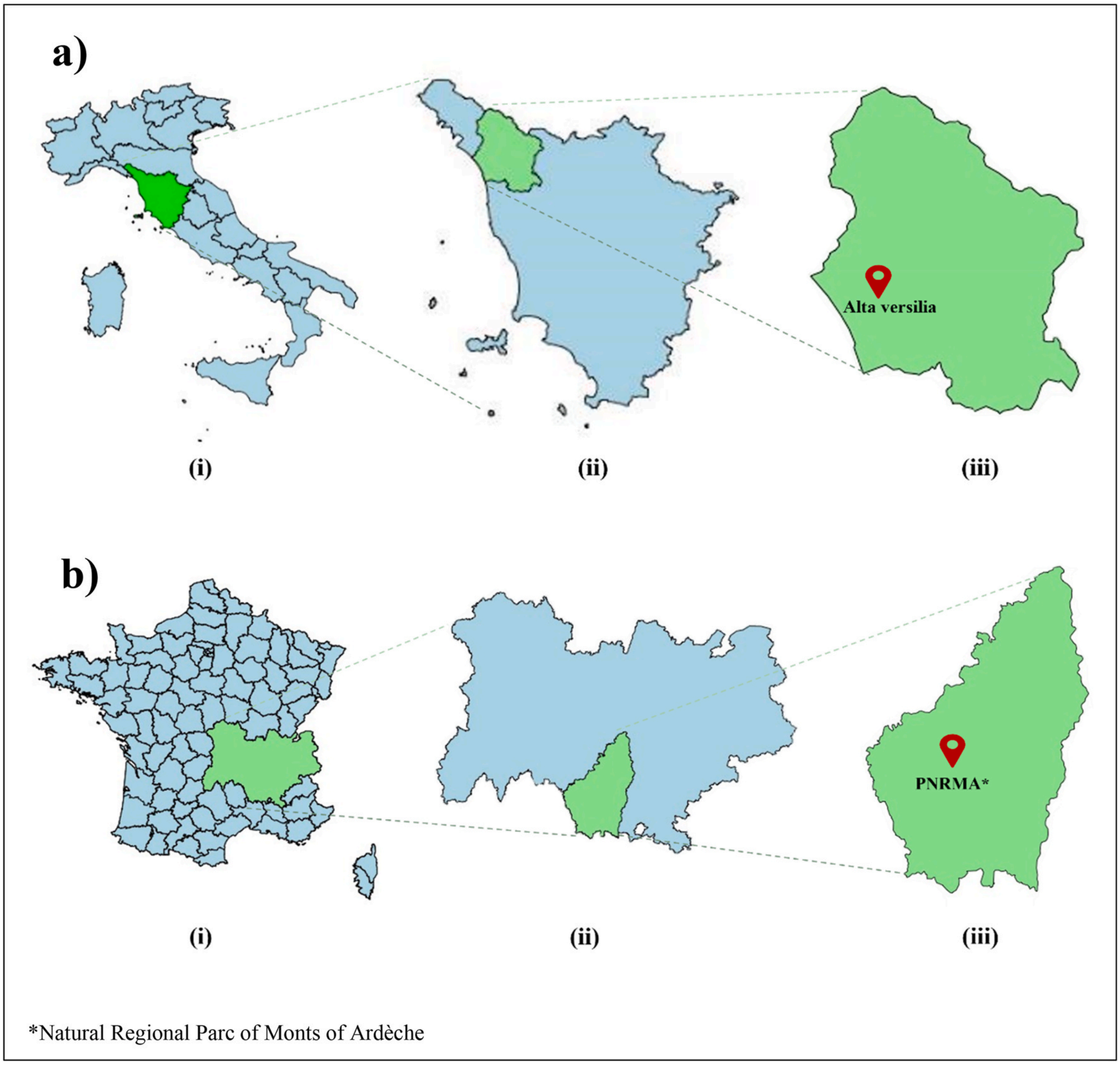

Fig. 2. Location of the two case studies – a) Map of (i) Italy, (ii) Tuscany, and (iii) Lucca; b) Map of (i) France, (ii) Auvergne-Rhône-Alpes, and (iii) Ardèche.

final outcomes.

The table demonstrates that there are numerous commonalities between the two VCs. To begin with territorial capitals, we see that the same forms of capitals are involved along the two VCs' stages, except for the French case where more sophisticated means are used at the processing stage. Concerning the actors involved and their practices, Table 4 reveals that actors in Ardèche (public or private) are more diversified compared to the Tuscan ones. Interestingly, this actors' diversity implies a direct and deep involvement of local and regional authorities in the French chestnut VC which are engaged in several practices not detected within the Italian case (i.e., promoting for certifications & labels, more diversified derived chestnut products, etc.). For what concerns flows and values created, it is noteworthy to remind that the value created is related to the availability of territorial capitals, that is why the two VCs reported almost the same values and flows at the first two stages, while we have found some differences after the processing stage. Besides the similarities between the two cases, the differences detected are mainly due to the diversity of actors involved and their practices. Additionally, the certification process also contributed significantly to differentiate the two cases.

3.2. Overall sustainability

As could be seen from Fig. 3, given that a score of 5 as best and 1 as lowest or unacceptable, the French chestnut VC has a better overall score compared to the Italian one for the four sustainability dimensions, in addition to the assemblage analysis, where the French case assemblage performs better than the Italian one. The dimensions in which the French VC performs clearly better are Good Governance, Environmental integrity, and Economic Resilience. While, both VCs scored low for the social dimension. In the next part

Table 4
Value chains analysis and TEEB application.

	Production		Processing		Distribution		Consumption		OUTCOMES	
	Lucca (IT)	Ardèche (FR)	Lucca (IT)	Ardèche (FR)	Lucca (IT)	Ardèche (FR)	Lucca (IT)	Ardèche (FR)	Lucca (IT)	Ardèche (FR)
Territorial Capitals	Perennial chestnut trees Chestnut cultivation knowledge; Access to groves' locations; Local Chestnut variety	Labels linked knowledge	Traditional drying buildings (metato); Mills;	Larger and more modern processing units; Harvesting nets; Vacuum cleaner;	Infrastructure; Territorial branding Marketing lines;	PDO label	Culinary knowledge (traditional recipes) Pasta shops; Festivals & other social events		**Economic**: Increased chestnut yield/Valorisation of linked products. **Socio-Cultural**: Social empowerment through cooperation between stakeholders/ Preserved traditional knowledge & cultural heritage/ Improved skills/ Fight against mountain areas abandonment **Environmental**: CO_2 sequestration/ Soil tenure/Silvic ecosystem restoration/ Maintained landscape	
Practices	Chestnuts' collection/harvest Sorting (selecting) best chestnuts	Organic Farming practices	Drying Peeling Sorting Milling	Drying Peeling Sorting Milling Transformation to different types of food (baking, caramelizing, glazing, etc.)	Packaging Direct selling Online advertisement	Packaging Online advertisement	On-farm sales; Selling to specialised shops; Restaurants;			
Actors	Small local farmers & Chestnut groves owner	Small local farmers & Chestnut groves owner Local/regional authorities Syndicate Natural Regional Park	Farmers Employees Association Mills owners Metato managers	Farmers Employees Collectors Industrial actors Associations Syndicate Local authorities	Farmers; Association	Farmers; Association Industrial actors Association Syndicate	Farmers Retailers Restaurants Hikers and tourists Local population (especially for Ardèche)			
Flows	Labour; Chestnuts; CO2 sequestration; Soil retention;		Labour; Wages; Chestnut flour; GHG emission from drying;		Packed products	Certified packed products	Chestnut flour (final product)	A variety of chestnut derived products (flour, jam, cream, biscuits, candies, beer, etc.)		
Values	**Economic:** Income from wildly collected goods (+ve).		Additional income from an appreciated product (+ve)		/	PDO and Organic certified products (+ve)	Premium from processed product (+ve). Gluten-free products (+ve)			
	Socio-Cultural: Preserved cultural heritage (+ve); Link with tourism sector (+ve).		More employment opportunities (+ve); Cooperation between farmers, associations, and mills' owners (+ve); Culinary heritage for both regions;		Spreading local socio-cultural habit (+ve); Employment opportunities (+ve)		Contribution to food security (+ve); Supply of a traditionally appreciated product (+ve)			
	Environmental: Nutrients' cycle (+ve); Ecosystems restoration (+ve); Pruning wood from chestnut used for drying, heating, and mulching (+ve).		Chestnut peel use as compost (+ve);		GHG emissions due to transportation (-ve)		Product's waste (-ve);			

+ve: positive/-ve: negative.

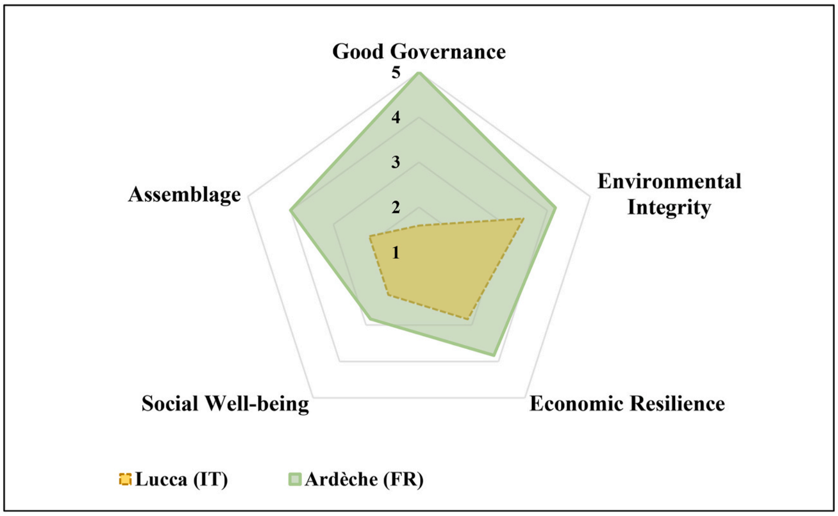

Fig. 3. Overall sustainability average score.

we will see the details of these differences and attempt to explain the reasons leading to them.

3.3. Sustainability scores by dimension

Fig. 4 provides an in-depth analysis of individual scores for each dimension and indicator, enabling a more detailed examination of the sustainability performance of both the French and Italian VC.

Following the same scale (5 as best and 1 as unacceptable), the French VC demonstrates better sustainability performances across all dimensions. However, it is noteworthy that the Italian VC performs better than the French one in certain indicators of the Environmental Integrity dimensions. In general, the Italian VC received lower scores, particularly in the social well-being and good governance dimensions. This is further reinforced by the assemblage analysis which also recorded a lower performance for the Italian VC.

On the other hand, despite its overall higher scores, the French VC exhibited low scores for certain indicators associated with the economic resilience, environmental integrity, and social well-being dimensions, such as cost of production, renewable energy, and support to vulnerable people, respectively. Clearly, these low scores are due to the absence of any practices to substitute fossil fuels, or to support individuals with special needs.

The higher environmental performance of the French VC can be attributed to two elements. Firstly, the organic and PDO (Protected Designation of Origin) certifications which are strongly linked to several good practices that enhance the environmental performance of certified operators. Secondly, the active role of PNRMA (Natural Regional Park of Ardèche Mounts) to engage with all stakeholders in the territory and raising biodiversity awareness and valorising natural resources.

Moreover, the French VC performed very high in the Good Governance dimension due to transparent dialogue and actor involvement in decision-making. This high score is explained by the fact that all VC's stakeholders are well and fairly represented at the decision-making circle. For instance, in a meeting organised to discuss a development project's budget and the organisation of subsidies distribution, all stakeholders were either present or had a representative. Once the meeting finished, the next day encounters and meetings took place to spread information and outcomes of the meeting among smallholders.

The Italian VC's advantage in the environmental integrity dimension is due to manual labour and water mills not relying on electricity or fuel. Furthermore, the Italian VC performs better for some indicators related to the economic dimension, such as production costs, price determination, market stability, and local procurement. This outcome can be attributed to the practice of chestnut's (small) producers setting prices instead of buyers, giving them higher bargaining power compared to French producers who engage into the practice of negotiating market prices with industrial stakeholders, where the latter set the price at the first place.

Overall, the outcomes of the analysis indicate that the assemblage in the French case is well maintained compared to the Italian case.

To begin with the Italian case, three broad themes emerged from the assemblage analysis. The typologies of actors involved in the assemblage are not diversified enough, since local/regional authorities are not represented at any level. Therefore, there is no concrete dialogue between private and public parts. Moreover, the knowledge about the practices conducted in the Italian case are transmitted from a generation to another or between stakeholders in informal ways, and no knowledge, trainings and/or extension support are offered on themes such as sustainability, biodiversity preservation, chestnut groves management. Finally, the operational legislative frame ruling access and management of the SES's resource units (i.e., parcels/groves), is inefficient as many interviewees raised land property and fragmentation problems. The assemblage analysis of the French case shows more promising outcomes. A more diversified range of actors involved in the assemblage has been reported; this allows the establishment of a transparent way of governance and an

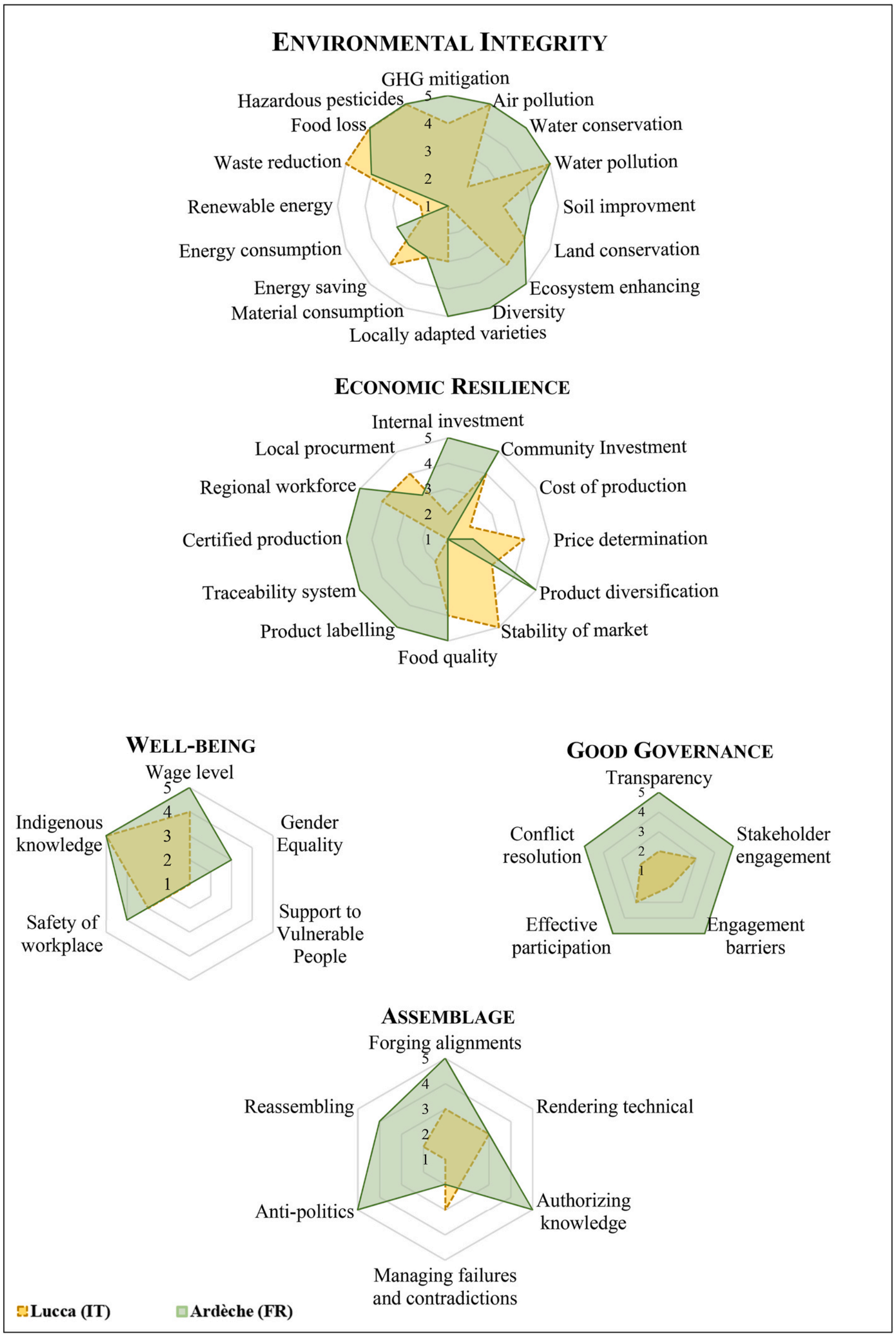

Fig. 4. Sustainability scores for individual indicators.

easily conducted dialogue between different parties (i.e., representatives of small producers, local and regional authorities, etc). The analysis of the assemblage allowed to verify actors' active engagement in knowledge acquisition and information sharing. Moreover, the Chamber of Agriculture offers trainings and extension sessions for other actors about different topics linked to chestnut production practices, natural resources and biodiversity preservation, marketing, and certification.

The two case studies share common beneficial aspects. Interviewees in both territories were able to identify the stakeholders they deal with, sometimes they even have records and contact lists of their partners. In their accounts and awareness of the surrounding situations, interviewees were able to suggest initiatives and practices to be grafted to the assemblage to improve its performance (e.g., involve academic partners, take part in research projects, reinforce partnership with local authorities, etc.). Additionally, stakeholders show a certain ambition by designing a variety of objectives, that are aligned with local and regional authorities' policies. The present elements seem to be consistent with the conclusions made by Murray Li [43] in their study about maintenance and success of assemblages.

Ultimately, a few indicator-based frameworks and tools were built to be more holistic and cover the three sustainability dimensions (e.g., SAFE, COSA, RISE) [18,19]; however, none of them has considered the dynamics of the system through the social practices conducted by actors along the VC. For instance, the SAFE framework (Sustainability Assessment of Farming and the Environment), although it covers the 3BL and based on sets of indicators, it is still static and evaluate these indicators based on pre-set thresholds instead of actors' perspectives [61]. While COSA, as one of the most used tools to assess sustainability, it covers all dimensions as well, but it is very limited and applied only to a couple of crops [20].

4. Conclusions

This research was undertaken to design a novel framework to evaluate agri-food VCs' sustainability. Significant findings emerged from our study. First, the proposed framework synthesizes various concepts and integrates the use of established sustainability assessment frameworks to create a more comprehensive and robust approach for evaluating sustainability at the VC scale. This framework aims to address the limitations identified in previous studies and provides a more holistic and dynamic perspective on sustainability assessment. It considers concepts, such as assemblage and socio-ecological systems, and it focuses on the crucial role of stakeholder engagement and their relationship with the environment. Accounting for these innovative attributes, the proposed framework provides a valuable contribution to the field of VC's sustainability assessment. Second, the user-friendliness, the simplicity, wider scope, and broad spectrum of dimensions included in addition to the emphasis on human-human and human-environment relationship are also key features of the new framework. Third, the discussions conducted while interviewing stakeholders were a great opportunity for expertise exchange and knowledge sharing, which emphasises the significance of the rural extension purpose of the new framework. Moreover, another major discovery from our study is that, though we considered two similar VCs that exploit the same territorial capitals and create the same value and final outcomes, we could get different levels of sustainability.

Two major elements can explain the better sustainability performance of the French case: the implementation of certifications and quality labels, and the devoted engagement of various stakeholders in the governance of the VC. Compared with the French VC, the Italian VC resulted in higher scores for several indicators (e.g., price determination, energy saving, etc.), despite its lower overall sustainability performance. This indicates that there are several initiatives/strategies that can be operationalised to improve current sustainability performance.

The new framework was successfully applied to real-life case studies and has shown its effectiveness in addressing the challenges faced and demonstrates its potential for widespread use in similar scenarios. The most significant limitation of the study is the absence of consumer perspectives, which was not obtained through the interview phase and represents a gap in the VC analysis. Therefore, consumers' point of view shall be considered in the future by improving the new framework into a more inclusive model that covers more aspects including consumer-related indicators. Further research is recommended to validate the framework's efficacy in another context.

Data availability

Data associated with our study has not been deposited into a publicly available repository and will be made available on request.

CRediT authorship contribution statement

Tarek Allali: Writing – original draft, Methodology, Investigation, Data curation, Conceptualization. **Manola Colabianchi:** Investigation, Data curation. **Michele Moretti:** Writing – review & editing, Validation, Methodology, Conceptualization. **Gianluca Brunori:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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