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Research article

Fuel for collective action: A SWOT analysis to identify social barriers and drivers for a local woody biomass supply chain in an Italian alpine valley

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ABSTRACT

The role of woody biomass in the clean energy transition is substantial in the EU. Forest residues are one of the main biomass sources that can be used for energy production, but their use to support the energy transition is still limited for several reasons. Research has shown that the use of forest residues in energy production can be effectively stimulated through collective actions that aim to develop short and local supply chains. This study aims to identify the barriers and drivers for the development of a local supply chain for forest residues in an Italian alpine valley, gathering and analysing the perspectives of all involved local actors, that is, (i) suppliers - the communities that own the forest resources, (ii) intermediaries - the forest professionals providing extension and advice services to owners and the harvesting companies; and (iii) the final consumers, in this case the local municipalities and hospitality enterprises. Data are analysed using a SWOT analysis. The results show that the suppliers identified opportunities especially, while the final consumers focused more on strengths, weaknesses, and threats. The SWOT categories in terms of the number of different factors were weaknesses (37 %), strengths (27 %), threats (18 %), and opportunities (17 %). Opportunities and strengths were considered as drivers, while threats and weaknesses were barriers. Several drivers emerged, such as a general predisposition toward the development of a local supply chain for forest residues, social homogeneity in terms of knowledge and management of the land, and common challenges. Barriers also emerged in the form of limited know-how on the supply chain potential, but also in limited availability to concede control between different forest owners over their property. The SWOT results are useful to design strategies to support the development of the supply chain: four possible strategies, amongst which flexible cooperation processes between different categories of stakeholders, and the organisation of a buying group of the hospitality enterprises, were suggested.

1. Introduction

The incumbent threat of climate change is directing governments, civil society, industries, and citizens to push towards the use of renewable energies and bioenergy. The latter, given its positive impacts in mitigating climate change and achieving net zero targets through the energy transition [1,2], is expected to play an important role in the next mix of energy of developed countries up to 2050

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[3]. In this context, biomass used for heating and energy production has great potential to contribute to the reduction of emissions and rural development on the EU scale. A major example of the recognition of the important role of biomass in the energy transition is the Directive RED II (2018/2001) of the European Union (EU). The EU recognises a key difference in the use of different types of biomass. In fact, REDII directs the EU states to achieve renewable energy, including biomass, production targets using a cascade approach, which aims to maximise resource use by using 'biomass for products of higher value, first as material input, before using it as an energy source' [4]. Italy, driven by European policies, has also implemented numerous policies [5,6] that encourage the use of bioenergy [7]. However, despite evidence of a growing trend in bioenergy use in the country [7] and support from customised policies [8], some regions with high potential for bioenergy production have slowed their growth in bioenergy production since 2012 [9]. This shows that there are issues in the development of forest residue supply chains.

Among the types of bioenergy, forest-derived biomass plays a key role, especially in heat production. Currently, only 22 % of heat production comes from renewable energy sources, but 85 % of renewable heat comes from heat produced from biomass, mainly (90 %) from solid biomass, which is made up primarily of forest biomass [10]. The present paper focusses on biomass coming from forest residues, including tree tops and branches from thinning and felling operations [5]. It has been estimated that the amount of forest residues produced through a regular harvesting operation is approximately 20 % of the wood extracted from forests [6]: therefore, even if from the point of view of timber production, forest residues are generally considered simply a waste or even an unwanted by-product, from the point of view of energy production, they can play an important role in bioenergy production [11–13]. Forest residues are commonly used throughout the world [14], and there is evidence for room for improvement at the European level [11]. In fact, despite the recognised advantage of providing value to a neglected byproduct, the possibility of building effective supply chains for forest residues is currently hindered by several factors. The development of forest biomass supply chains for energy production depends on many factors that belong to four categories: logistics, environmental, economic, and sociopolitical. Logistics factors, such as road development and types of forest operations, are well documented in the literature [12,13,15–17]. Among environmental factors, impacts on air quality and the risk of losing taxa of special concern due to changes in land use are included [18], although the risk of change in land use could not apply in the case of forest residue use. Environmental sustainability can be improved by developing short wood supply chains, due to the limited transportation distance, [19]. However, this is not enough, as there are other elements to consider to achieve environmental sustainability and they are not closely related to each other [7]. For example, environmental sustainability is highly dependent on the choice of feedstock, land management, and change in land use, and the conversion of feedstock into the energy process [2,19]. The size of the biomass power plant also impacts the environmental sustainability of the supply chain. Paletto et al. [20] observed that medium power plants had lower impacts than small power plants. That is because medium power plants can use forest residues from local forests, compared to smaller plants that have to use only sawmill woodchips, which are more likely to have foreign origin. Therefore, the impact of transportation is higher in the latter case [20]. The type of biomass used for the production of bioenergy can also play a role.

In general, despite being often environmentally sustainable, local supply chains, especially those that deliver products for the production of bioenergy, are not always economically viable [21].

Amongst economic factors, the level of income of the final consumers responsible for demand [22], inefficiencies in the use of biomass [23], and general economic trends that influence energy prices [24] contribute to the development or failure of supply chains. The demand for biomass for energy can also be driven by regulations and policies, including financial incentives at the national level [25].

Finally, a fourth group of factors that affect the development of bioenergy supply chains is the social dimension [9], supported by a growing literature studying the social sustainability of biobased supply chains [26]. Krupnik et al. [27], among others, observed that the implementation of a local renewable energy supply chain is more related to power asymmetries, ownership, and socio-spatial conflicts than to energy itself. Although social aspects have been highlighted as necessary to be better integrated in energy system studies [28,29], the role of social aspects in the development of a biomass-based supply chain, and, particularly, in forest-related supply chains, has not yet been sufficiently studied [29,30].

To fill this gap, we focus on analysing the social dimensions of the development of a local supply chain based on the use of forest residues as a possible contributor to the development of a local heating system at the district level. The specific objectives of our study were to:

1. Identify the social drivers and barriers to the development of a short supply chain using biomass from forest residues in an alpine valley. We approach the problem with a focus on the collective actions needed to build an effective supply chain and explore the perspectives of the supply chain actors on using individual heating systems versus district heating systems.
2. Propose possible strategies to overcome identified barriers, with a focus on strategies to promote collective action between actors.

In addition to this introduction, the paper is structured into five other sections: Section 2 is a short review of the literature on the social dimensions of supply chains and collective action. Section 3 reports the materials and methods, including the descriptions of the study area and the methods and tools for data collection and analysis (SWOT Analysis). Section 4 presents the results organised in the SWOT matrix and provides in-depth insights into the collected data, also discussing them in connection with the international literature. Section 5 suggests possible SWOT strategies, as a practical outcome of the study in line with Rauch [31]. Finally, Section 6 draws the conclusions of the article.

2. Literature review

Due to the forest residues for energy being a niche and the general lack of attention on the social aspects on the biomass for supply chain development, we conducted a literature review focussed on forest residues for energy to understand the state of the art and to frame the results from our case study in an international context.

We approach the review from two perspectives reflecting the objectives: (i) social barriers and drivers for the development of a supply chain for biomass for energy, focussing on forest residues, and (ii) collective action as a means of developing the supply chain at the local scale.

For general social barriers and drivers, the main strings of the literature review on Scopus (Fig. 1) were as follows:

1. "social dimension" AND "biomass" AND "supply chain": 6 results,
2. "socioeconomics" AND "bioenergy" OR "forest biomass" AND "supply chain": 4 results.

Regarding collective action in the context of biomass supply chain development, we carried out a separate search (Fig. 1). In particular, in this case, we use

- "collective action" AND "biomass" OR "forest residues" AND "supply chain*"- 3 results.

Adding "collective action" as a keyword to the first two strings did not give any results. We used other keywords in the two strings above, which did not yield any relevant results. The keywords used were "social barrier", "social driver*", "forest residues", "social dynamics" and "energy".

To further improve the literature review, for both perspectives, additional studies were included outside the Scopus database, and this information was added to the section.

The results of the review show that, to date, the literature has rarely focused on social aspects of forest residues energy supply chain development. However, there is more research on biomass supply and value chains in general terms.

The literature on the social dimension of bioeconomy [33] can provide a general overview of the factors that influence the use of bioenergy in terms of drivers, barriers, and impacts. These factors can be health and safety, social acceptability, human rights, labour rights, and decent work [33].

Domac et al. [34] analysed socio-economic drivers for bioenergy projects. The impacts of the development of the biomass supply chain are often linked to increased standards of living related to health, the environment, regional development, rural diversification, and migration effects [34]. Most often, the main socioeconomic driver associated with a bioenergy project is the creation of jobs and the reduced cost of unemployment [35,36]. Population density is also considered [37] especially related to communication between people and increased interaction, leading to the sharing of technology and the development of innovations [9]. Self-sufficiency in energy production, as well as in energy security, is considered another relevant social factor [36]. However, political choices at the local level have been considered as possible drivers and barriers [38]. Social sustainability has been evaluated in a model proposed by

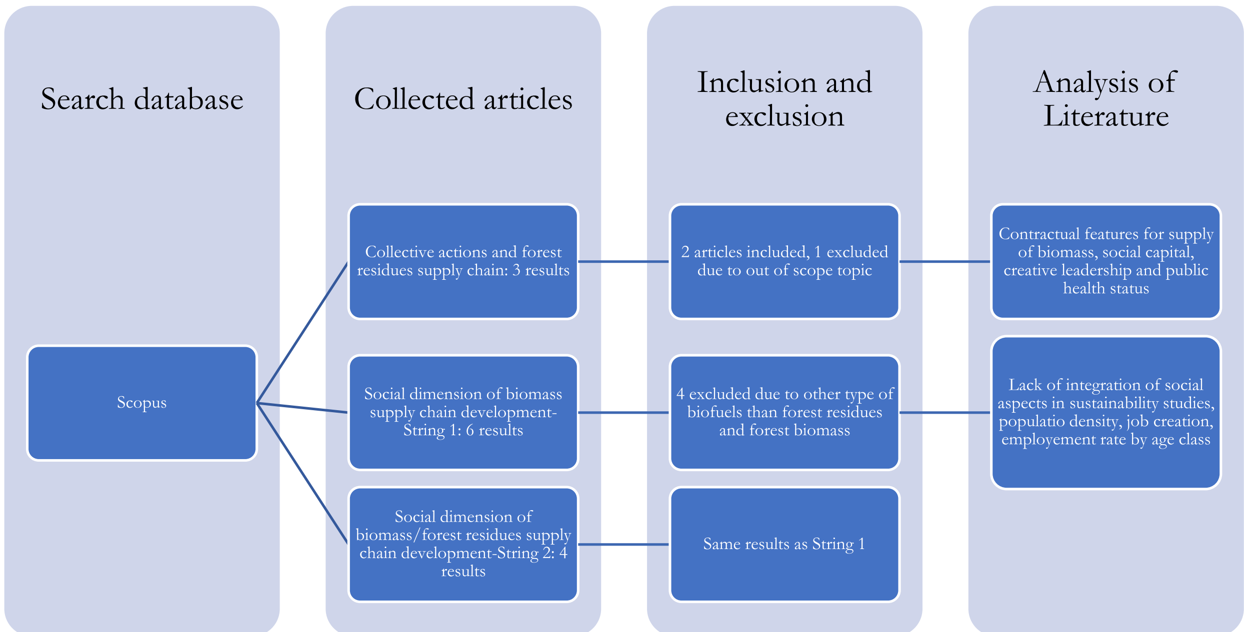

Fig. 1. The literature review process was modified from that of Hiloidhari et al. [32].

How and Lam [39] but limited to the health and safety of operators in the supply chain. More studies are available on the social dimension of biomass for the energy supply chain for the case of agricultural biomass, for example [40].

One of the main social factors that can affect the development of supply chains is social acceptance [41]. Social acceptance comprises multiple factors for the development of the energy supply chain, and its concept partially overlaps with the category of categories of factors related to the development of the general social dimension related to the development of the energy supply chain. Social acceptance is associated with the social behaviour [41] of stakeholders and actors in the supply chain. Social acceptance of bioenergy development can be increased by awareness of climate change, its impacts, and knowledge of how technologies for renewable energy work [41]. Social acceptance can be approached through three dimensions: sociopolitical acceptance, community acceptance, and market acceptance [42]. Socio-political acceptance is acceptance by the public, key stakeholders, and policy makers [43]. Community acceptance is the acceptance of local bodies, municipalities, authorities, associations, and organisations, mostly at the local level [43]. Finally, market acceptance refers to the adoption of a new technology in a market such as the bioenergy market [43]. In the case of the development of the bioenergy supply chain at the local level, social acceptance can be analysed through all three dimensions. Forest owners, as suppliers, can be part of both the community and the market. In the case of community-owned forests, they can also belong to the socio-political dimension of acceptance. Forest owners are generally believed to be able to provide biomass for energy production [44–46]. A positive attitude in the harvesting of biomass, such as residue, for energy can be induced by social factors, such as knowing who to call for the job. In general, limited knowledge of the practices of wood biomass for energy production can cause uncertainty in biomass supply [47]. However, participation in education and training programmes can support forest owners in collecting biomass for energy [44,45]. Forest owners can oppose the idea of using their forest resources for energy production. Paletto et al. [48] showed that forest communities in an area in northeast Italy disagreed with the use of wood biomass for energy production, as it was against the traditional and social needs of local communities. Blennow et al. [49] showed that private forest owners in Germany, Portugal, and Sweden were reluctant to change their management plans to supply stemwood for energy production. The opposition to the use of biomass for energy purposes appeared to be related to the use of wood for energy production and not to the use of by-products such as forest residues. The position of influential intermediaries can affect the acceptance of supply chain development. For example, forest professionals are often aligned with forest owners, stressing the importance of biomass as a by-product of forest management [50]. In general, the acceptance of each group of actors in the supply chain can be influenced by specific factors. In the case of consumers, strategic considerations of fuel security supply and administrative issues related to grid connections influence the decision to join district heating systems [51]. Institutional consumers, such as municipalities, are influenced by physical, economic, and technical factors, including policies, when deciding to use biomass heating systems [52].

For the development of a local supply chain based on forest residues, collective action between local stakeholders, such as supply chain actors, appears to be fundamental and is also promoted at the EU level [53]. Two studies directly addressed collective action in the context of forest residues or biomass supply chains for energy. Martinkus et al. [54] selected three elements of collective action and collaborative capacity that potentially influence each other: social capital, creative leadership, and public health status. These three elements impact the capacity for collective action of communities. The second study [55] analysed how specific contractual characteristics of a bioenergy supply chain can trigger collective action to manage and coordinate this supply chain. Many studies have addressed collective actions from other perspectives, such as cooperation and coordination. The concept of coordination is strictly related to cooperation. For example, cooperation allows efficient allocation of forest residues and reduces transportation distances,

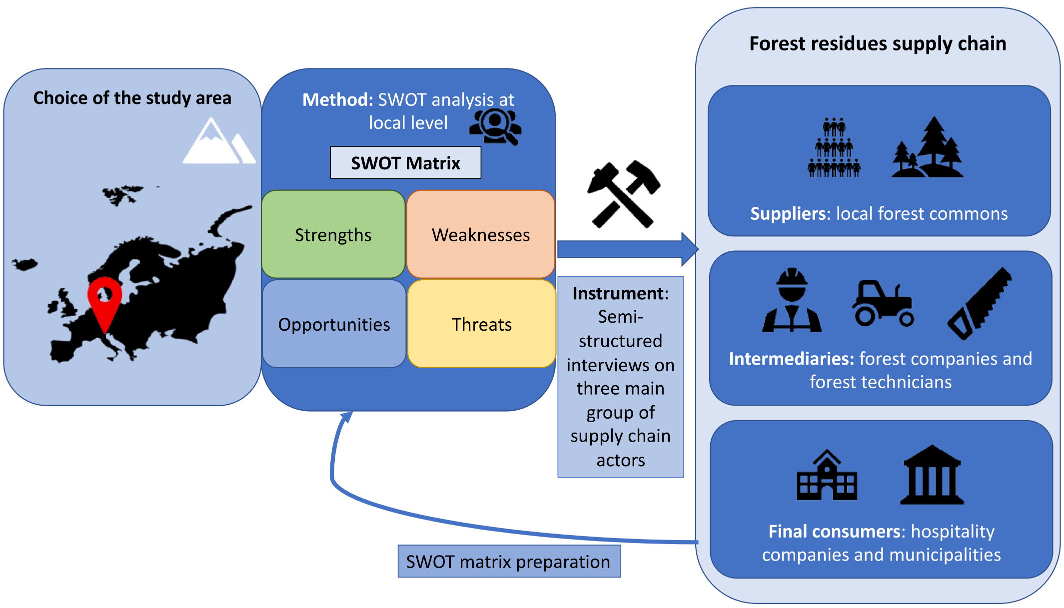

Fig. 2. The four main steps of the methodology.

thus reducing forest fuel transportation costs [56]. Cooperation is a basic element of coordination and is strongly related to the dynamics of collective action dynamics; this process is an emerging topic in the literature on small and dispersed communities for the development of biomass supply chains [57,58]. Coordination between the players in the biomass supply chain is essential for the long-term sustainability of the process [59]. The coordination between stakeholders in the biomass supply chain is also supported by Rösch and Kaltschmitt [60]. Collective action depends on the positioning of supply chain actors on the topic of forest residues and the general use of biomass for energy, specifically heat production.

3. Materials and methods

Our methodology was structured in four main steps (Fig. 2): 1) the selection and description of the study area, 2) the choice of method, SWOT analysis and instrument, 3) the selection of supply chain actors and the preparation of semi-structured interviews for each category of actors, and 4) the analysis of the interviews for the creation of the SWOT matrix.

3.1. Study area

According to Panoutsou et al. [61], the choice of a specific case study area is related to the need to better illustrate the local specificities of a localised supply chain and inform policy makers [62].

The Comelico Valley is located in northeast Italy, in the Veneto region (Fig. 3), within the mountain range of the Alps. The Comelico Valley comprises five municipalities located in an inner area, 'a rural area far from the main services' [63]. Inner areas are addressed by a national policy, the Strategy for Inner Areas, which requires that each inner area officially designate its own Local Strategy for development. The inner areas, which are rural areas, are often located where energy consumption for heating is high [62]. The use of biomass for heating can support the social, environmental, and economic development of rural areas [62], and fossil energy sources are difficult to exploit for logistical reasons. The Comelico Inner Area (Comelico IA) fits these criteria to develop a local supply chain of forest residues. Local supply chains can increase the convenience of recovering biomass from forest residues for use in district heating or power plants [64].

Private forest owners are key figures involved in any initiative or policy to maintain or improve the provision of biomass for energy, either for electricity or heating production. In Italy, 66 % of the country's forests are private [65]. In the Veneto region, 71 % of the forests were private, 12 % of which are of the Regole, a typical form of community-institution owning forests [66], described by Favero et al. and Gatto & Bogataj [67,68]. In Comelico IA, most of the forest (70–80 %, approximately 13.400 ha) is owned by the Regole [69] and is actively managed.

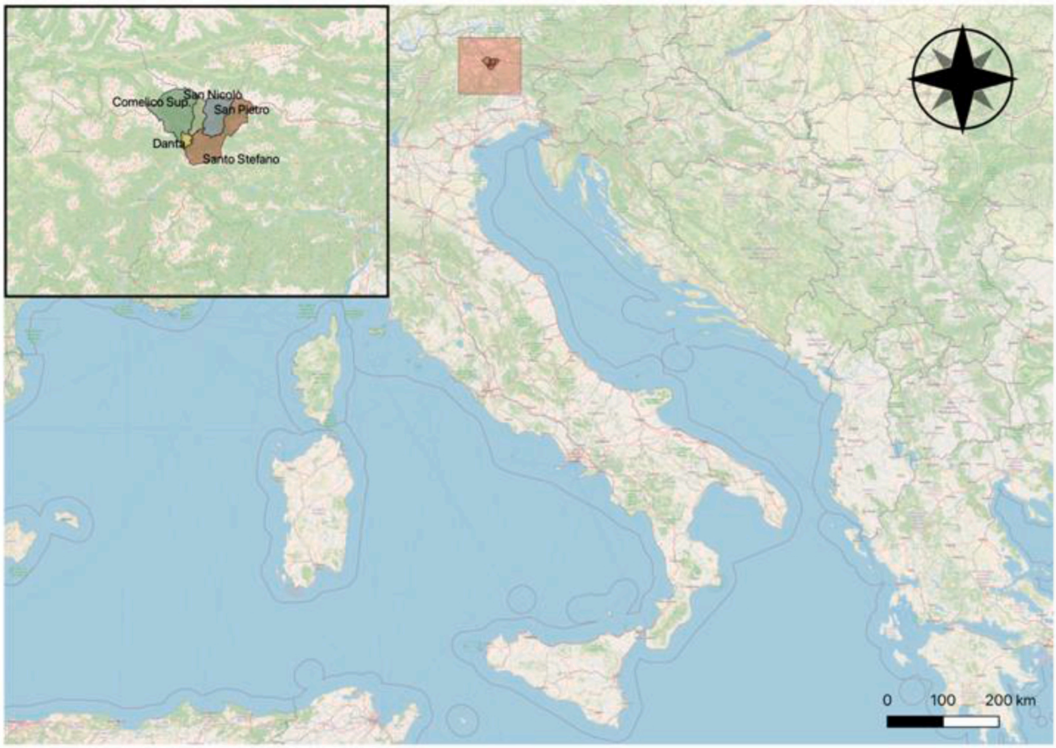

Fig. 3. A map of the five municipalities of the Comelico Valley.

Despite active forest management, forest residues are largely underused in Comelico IA [70]. Until today (2023), forest residues in Comelico IA have been mostly left out of contracts with forest companies, with a few exceptions. In our study, forest companies are harvesting contractors. Timber is sold primarily to local forest companies (Regole presidents, 2023, personal communications).

A rough figure of the quantity of forest residue production in Comelico IA, mainly in high-altitude forests, can be estimated based on the percentage of forest residue in the cutting volume (25 %) of the province of South Tyrol [71], adjacent to our study area, and consistent with the European estimate in Camia et al. [6]. Based on this literature and using the volume-weight ratio reported by Francescato et al. [72], and referring to the highest coefficient for moisture content (50 %) for the main species present in the study area, i.e., spruce (*Picea abies*), the potential production of forest residues [73] in the 13.400 ha owned by Regole could reach 6.700 tons/year. The consumption of the Comelico IA power plant is reported to be 1.700 tons/year [66].

Comelico IA is also an interesting study area because it has a district heating system in one municipality, but the Comelico IA Local Strategy highlights an issue with an overabundance of forest residues, which apparently were not used in the district heating power plant.

In Comelico IA, two forest companies regularly process forest residues, but only one has built its entire business to produce wood chips. Both forest companies have more than five employees each, which is atypical for the Veneto region, where forest companies are generally smaller (1,6 employees per company) [66]. There is no current cooperative action or any form of collective action in the field of biomass for the Comelico IA energy supply chain.

3.2. SWOT analysis

Strengths, weaknesses, opportunities, and threats (SWOT) analysis represents a valuable tool for strategic planning. SWOT examines the internal strengths and weaknesses of organisations and highlights the opportunities and threats provided by the context in which the organisation is established [31]. SWOT addresses two main classes of factors: internal factors, strengths, and weaknesses; and external factors, opportunities, and threats [73].

SWOT was developed for use within an organisation but can also be applied at the regional scale [74,75]. When SWOT is applied on a larger scale than that of a single company, the classification of the variables, that is, the elements of the SWOT matrix, is different. The usual macroenvironmental forces that are external factors for single companies can become internal factors in a larger study area. Because respondents, mainly managers, are different and have different objectives and activities, variables can be opportunities or threats, and strengths or weaknesses based on the characteristics of different managers among supply chain actors [76].

The drivers for the development of a local supply chain for forest residues are identified in strengths and opportunities, while barriers are mainly linked to weaknesses and threats.

3.3. Interviews and selection of respondents

All supply chain actors were identified as owners or operators working in the Comelico IA according to the Comelico IA Local Strategy [70].

Regole presidents and vice presidents were identified because of their public role in the local community. Forest companies that used biomass were identified via expert consultation with the Presidents.

Hospitality companies as potential final consumers were identified from the list of associates of the Comelico Valley Tourism Consortium.

Each potential respondent, including the municipality, was contacted by email to explain the study and request a face-to-face interview. We also contacted potential respondents after one week without responding. We managed to interview 11 representatives of Regole out of 15, 2 out of 2 forest companies dealing with the processing of forest residues in the area, 1 out of 2 forest professionals working in the area, 14 out of 35 hospitality companies associated with the local Tourism Consortium and 2 municipalities out of 5 of the study area.

Four types of semi-structured interviews (Table 1) were prepared for the four categories of supply chain actors summarised in

Table 1
The structure of the four different semi-structured interviews.

Primary suppliers	Intermediaries-suppliers	Private final consumers	Public final consumers
Priorities on the topic of biomass for heating	Priorities on the topic of biomass for heating	Priorities on the topic of biomass for heating	Priorities on the topic of biomass for heating
/	Characteristics of the Company	Characteristics of the structure	Characteristics of Municipal Structures
1. Strengths (from a supplier perspective) of the current use of forest residues 1. Weaknesses 2. Opportunities 3. Threats	1. Strengths (from an intermediary-supplier perspective) of the current use of forest residues 2. Weaknesses 3. Opportunities 4. Threats	1. Strengths (from a private consumer perspective) of current forest residues use 2. Weaknesses 3. Opportunities 4. Threats	1. Strengths (from a public consumer perspective) of the current use of forest residues 2. Weaknesses 3. Opportunities 4. Threats
Attitude towards cooperation with other suppliers in the supply chain.	Attitude towards cooperation with other actors in the supply chain	Attitude towards cooperation with other private consumers in the supply chain	Attitude toward cooperation with other public consumers in the supply chain

Table 2
Interviews for each type of actor within each category of actors in the forest residue supply chain in Comelico, IA.

Categories of Supply Chain Actors	Type of actor	N° of interviews/ total actors in the study area	Respondents	Notes
Primary suppliers	Regole (forest owners)	11/15	2 Vice Presidents and 9 Presidents	
Intermediaries	Forest companies (working with forest residues)	2/2	1 owner 1 chief of administration	Based and operating in Comelico IA
	Forest Technicians	1/2	/	Based and operating in Comelico IA
Private final consumers	Hotels B&Bs	14/35	Managers/Owners	6 hotels and 8 B&Bs. Selection based on high-energy consumption infrastructures, consistent with Spinelli [78]. 10 out of 14 final consumers reported using biomass-based heating devices.
Public final consumers	Municipalities	2/5	1 Mayor 1 technical officer	1 municipality is currently using a central wood chip boiler to heat public buildings that are all close to the main structure. The other municipality has a project to install a wood chip boiler for the public school.

Table 2. English versions of the interview guideline questions are provided in Appendices A, B, and C. The final consumers were also asked whether they preferred district heating systems as a community heating system or direct heating as an individual heating device and to express their opinions on SWOT elements for their preference. The interviews focused on collective action issues in supply chain development, but context-related questions were asked to provide a detailed context and allow the respondents to express their opinions on the subject.

The interviews were recorded with the respondent's written permission and transcribed via the NVivo Transcription module. Content analysis was performed with the aid of NVivo 14. The coding process was an inductive-deductive procedure [77]. Some codes were generated a priori (deductively) based on interview questions. Data-driven codes were created to summarise and categorise information to reflect the variety of responses to the questions.

3.4. *Development of strategies*

The section on strategies was used to address possible practical implications of the study according to the rural development framework under which it was carried out, the National Strategy for Inner Areas. The structure of the results and a preview of the policy strategy advice items are shown in Fig. 4. The strategies are elaborated based on the results of the SWOT matrix.

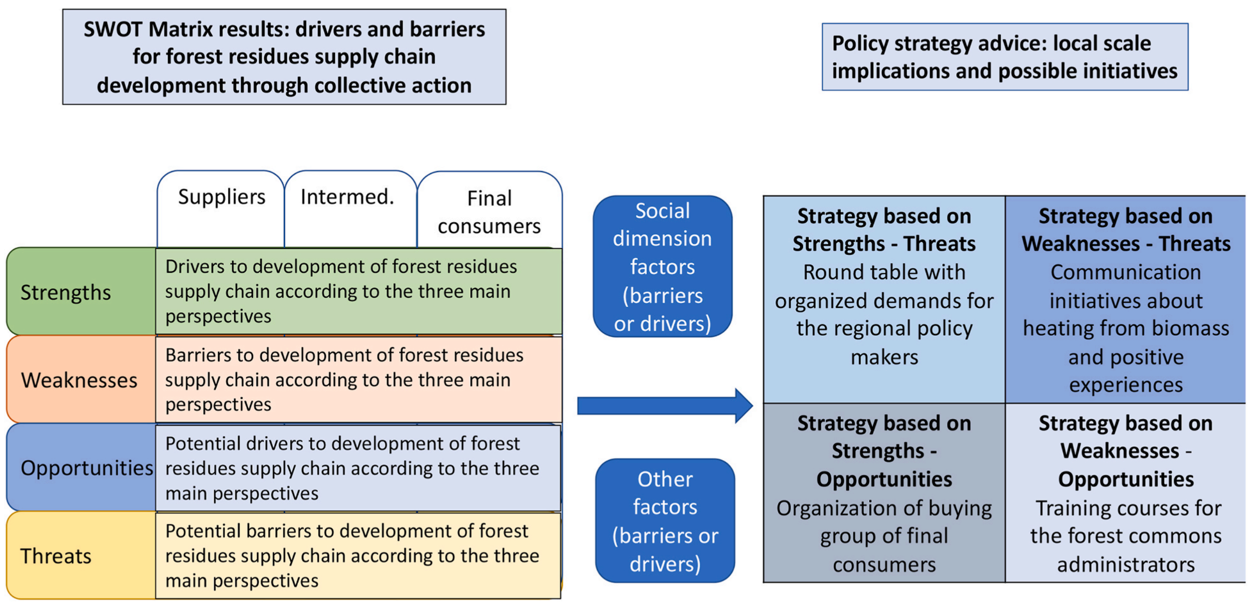

Fig. 4. The organisation of the SWOT matrix, the two subsections of the content analysis of the SWOT matrix, and the policy strategy advice elaborated from the SWOT matrix.

4. Results and discussion

Our aim was to identify the factors of social dimension that hinder or support the development of a local supply chain of forest residues for heat production through a collective action process in a specific area. The area, Comelico IA, represents an interesting case study given its geographical, social, and economic characteristics. In particular, our study analysed the opinions and perspectives of important actors in the local community in terms of drivers, barriers, and expected impacts to develop a short supply chain for forest residues. The local scale is relevant for studying energy transition processes [79], such as those involving the transformation of fossil fuels to biomass. Local-scale analysis allows one to understand the limits of national ambitions when implemented locally [80,81]. Therefore, improving local knowledge of what slows the growth of bioenergy supply chains and district heating systems, or individual ones, could help overcome some of these issues.

Our results are organised into two subsections: i) the SWOT matrix (par. 4.1) and ii) content analysis of the interviews and of the SWOT matrix (par. 4.2). Content analysis is structured to present the social drivers and barriers to the development of a local supply chain for forest residues, including a perspective of collective action. We discuss our results by presenting a comparison of the international literature.

4.1. SWOT matrix

The interviews generated a list of strengths, weaknesses, opportunities, threats, and SWOT elements according to the actors of the potential local supply chain. Strengths, weaknesses, opportunities, and threats were organised into a matrix, as shown in Fig. 2. The SWOT categories in terms of the coverage of the total factors were weaknesses (37 %), strengths (27 %), threats (18 %) and

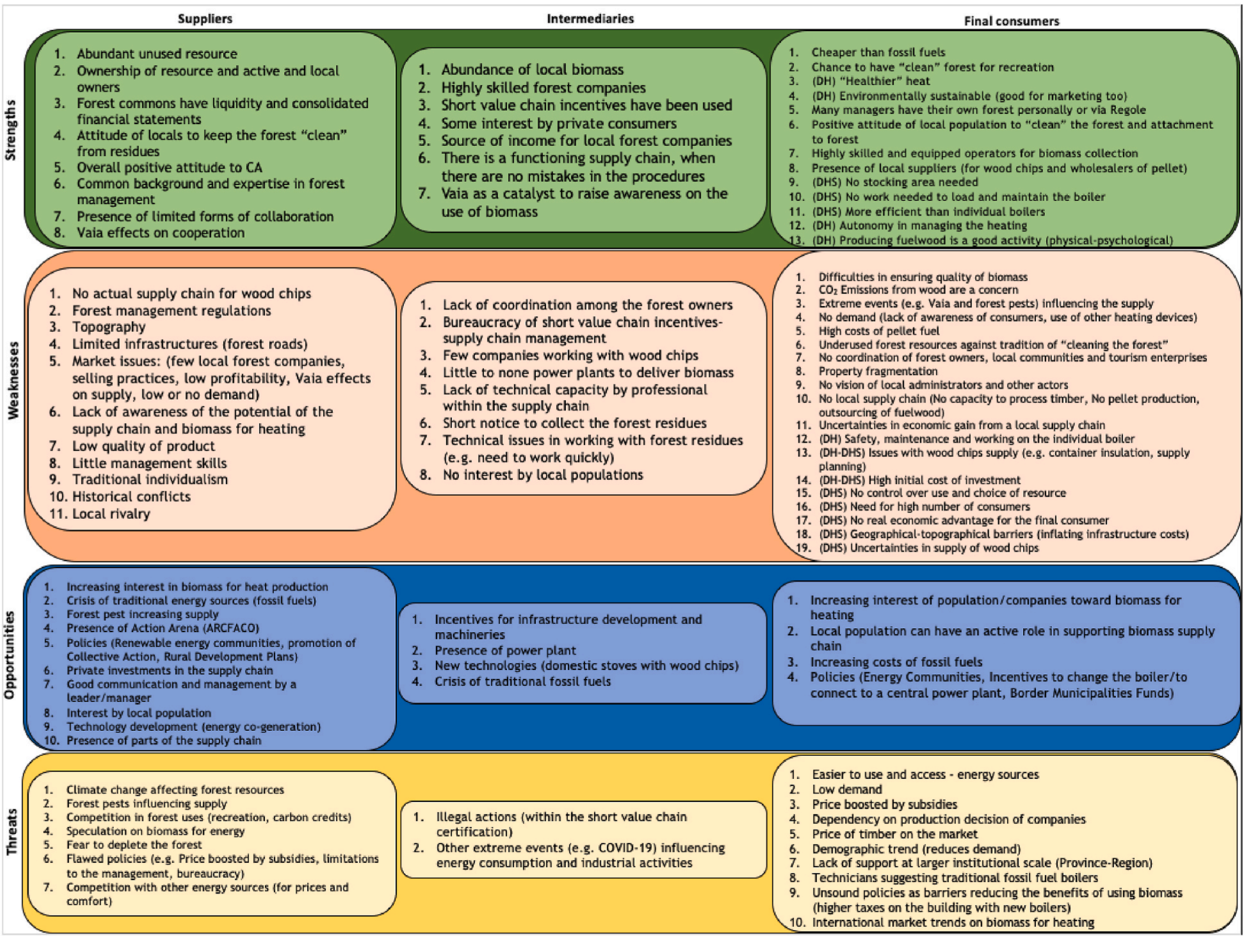

Fig. 5. The SWOT elements were organised by the category of the respondent who provided such a variable (supplier, intermediary, or final consumer) and according to the four main categories of variables such as strengths, weaknesses, opportunities, and threats. Each variable is coded according to its characteristics; for example, 'Ownership of resources and active local ownership" is coded as S2S (Strength, the number associated with the variable and the category of respondent, Supplier). DHS stands for the district heating system. DH stands for direct heating, which refers to an individual building/unit heating system.

opportunities (17 %). The final consumers, which were also the largest in number among the participants, identified the most strengths (46 % out of the total types of strengths identified), weaknesses (50 %) and threats (53 %). The suppliers, Regole, identified the most opportunities (56 %).

4.2. SWOT content on drivers and barriers to the development of a local supply chain

4.2.1. The role of knowledge about the supply chain

Analysis of SWOT content showed that there is a general lack of interest in the development of a forest residue-based supply chain due to its perceived low value in terms of potential revenues (W5S, W8I, W6S, W4FC, W11FC; Fig. 5). This perception resonated with the insecurity of suppliers and final consumers about the sustainability of forest residue processing linked to public subsidies (T3FC, T6S; Fig. 5). It should be noted that there is limited knowledge in the area about the potential revenues of investing in a forest residue supply chain. The feasibility of a supply chain was not investigated at the local level. This lack of awareness is even more evident when in several cases our respondents were mostly unaware of the biomass power plant in Comelico IA or doubtful about its efficiency. Two final private consumers complained about the lack of transparency in the construction and operation of the district heating system. These responses reflect the low institutional capacity, especially of the municipality where the power plant is located, to communicate and engage with the population, but also with potential supply chain actors. In fact, Upreti [82] found that a major source of public conflict over the development of biomass energy was related to weak public relation strategy of biomass developers. In Comelico IA, one municipality and a provincial energy company were part of the power plant developers. The level of knowledge and awareness of supply chain actors can affect their participation. The issue of low awareness at local level is addressed with Strategies 2–4 (Section 5).

In addition to awareness, know-how also plays a key role in the sociopolitical acceptance of biomass as energy. Know-how barriers are mainly represented by the lack or low level of expertise and technical capacity of the actors in the supply chain. A clear example is the limited knowledge by some actors in the supply chain on how bureaucracy works (W5I, Fig. 4). Bureaucracy involves documents, such as a map of the supply area, data of the forest owners, or authorisations from the forestry offices of the Region. Only intermediaries in the supply chain were considered experts in the field of biomass and forest residues for the production of wood chips, especially forest companies (S2I, S7FC, Fig. 5). Some Regole Presidents evaluated local forest companies as the most skilled actors in the potential supply chain, and this is consistent with the findings of Dautzenberg & Hanf [83]. Dautzenberg & Hanf [83] also observed that the most likely supply chain actors to initiate the supply chain are processing firms, because of their expertise in the whole supply chain processes. Despite their expertise, the role of forest companies as intermediary actors in the supply chain appears to be hindered by. Despite their expertise, the role of forest companies as intermediary actors in the supply chain appears to be hindered by different levels of know-how between the supply chain actors, according to one forest company employee. The low average expertise among other actors in the supply chain, such as forest owners, but also forest professionals, can be explained by the complexity of the bioenergy market due to the need to know about biomass resources, supply systems, conversion technologies and energy services [84]. The issue related to the limited know-how and difficult bureaucratic procedures was addressed by suggesting Strategy 1 (Section 5).

Awareness of the potential of a local supply chain and know-how among key actors in a supply chain can increase social acceptance for the development of a local supply chain.

Engagement is relevant not only with the local population and potential supply chain actors, but also to attract private investors. When potential financial suppliers are not sufficiently engaged in the biomass sector, they are not likely to invest [85]. In fact, a key opportunity to overcome the low activity in biomass for the energy sector at the local level could be private investments, possibly from outsiders (O6S, Fig. 5). In addition, improving the supporting policies and tools could result in the development of local supply chains. Economic measures such as investment grants and subsidies (e.g. green certificates) can encourage the development of bioenergy [84]. Schifani et al. [55] showed that several contractual characteristics, such as personalization and safeguards for invested capital, can help incentivise collective action for the development of the energy supply chain. Schifani et al. [55] also showed how farmers are willing to collectively invest in the development of the biomass supply chain for energy, but conditional on assistance in capital investments. In the Comelico IA, final consumers often used public incentives and subsidies to cover part of the investment in a new biomass-based individual heating device. Although these measures were effective for households and small companies, such as hotels and B&Bs, the conditions of the financial framework conditions are often not well adapted to the needs of biomass producers, according to the findings of Falcone & Sica [85]. The need for small-scale investments for biomass producers, which requires long-term financing sources, is in contrast to the actual financing tools planned for larger-scale investments, as well as most of the financing tools planned for short-term investments [85].

4.2.2. The role of international, national, and local policies

The socio-political acceptance of biomass for energy can be influenced by other factors, external to the study area. The international, national, and regional policies were mentioned as drivers of the development of the supply chain by the final consumers, who benefitted from them. Furthermore, suppliers saw opportunities as regional and national policies such as Rural Development Programmes, Green Communities (Law 221/2015) and Energy Communities (Decreto Milleproproghe 162/2019 and the Border Municipalities Fund (O4FC, O5S, Fig. 5).

However, policies and regulations can also be barriers. Some Regole presidents observed that forest management regulations limit the production and harvesting of biomass for energy in the study area (W2S, Fig. 5). These limitations are mainly related to nature conservation policies, according to some common presidents. Nature protection measures have been shown to drive forest management choices [86], although they do not necessarily stop active forest management.

An example of limiting regulation was mentioned by a Regola president: in contrast to Austria, the closest foreign EU country to

Comelico, IA, clearcutting is prohibited in Italy. This limitation, as the well as low level of mechanisation of forest companies, hinders the economic feasibility of collecting and selling forest residues for energy production. A Regola president also mentioned the risk of increasing forest management limitations due to the creation of the carbon credits market. Perceived policy threats hindering supply chain development, such as risks related to the carbon credit market, came from personal experience, but it should be considered that carbon credit production relies on forest management choices that can increase carbon sequestration [87]. Therefore, active management that includes timber production would not necessarily be limited. From a collective action perspective, the lack of coordination policies between the supply chain actors represents a major barrier to the development of the forest residue supply chain [88]. Supply chain coordination is indeed a key barrier according to McCormick and Kåberger [84], and it has also been shown to be a major barrier in our study area (W1I, Fig. 5). A forest company owner observed how the Regole of Comelico coordinated with each other in the past for economic gain, but cooperation is currently limited. A Regola president mentioned an opportunity to cooperate: [There is a need for …] 'someone to hold the strings, someone capable of making diverse actors work together'. This need is consistent with that of Martinkus et al. [54]. Regole presidents can be an option for such a role of leadership, other than forest companies, as previously mentioned.

Böcher suggests that cooperative instruments are, in fact, valid policy instruments for the development of the supply chain [89]. Any tool aimed at supporting collective action and coordination should be developed to address the right motivation to take action collectively. In our case, a strong potential driver for the Regole to act collectively was an economic advantage in dealing with forest residues. Collective action did not begin, partly because of the lack of perceived economic advantage.

An example of collective action that could improve forest residues collection efficiency is the coordination of forest operations between the neighbouring Regole, which was not happening at the time of the study (W1I; Fig. 5). Coordination of forest operations can improve transportation management, which is the most expensive component of the biomass supply chain [90]. Coordination and cooperation between the Regole are addressed in Strategy 3 (Section 5).

4.2.3. The role of other external drivers and barriers

Other external drivers to develop a local supply chain were the fluctuations of the prices of fossil fuels. Respondents recognised price fluctuations of other energy sources as the main influencing factor in their decision to use or invest in biomass production (T7S, T3FC, T6S; Fig. 5). Three major events affected forest resources and energy prices before and during the present study: the Vaia storm in 2018 affected forest resources, the Covid-19 pandemic and the Ukrainian War in 2022 affected energy prices. The effects of the war, combined with the recent Covid-19 pandemic, affected the cost of traditional fossil fuels used in the area, diesel oil, and the prices of fuelwood and pellets. In fact, energy prices can play a role in modifying the decision to harvest biomass and increasing its use [91]. Energy crises in the past have been shown to drive the change from fossil fuels and oil to biomass-based energy systems for heating [92, 93]. Regarding such crises, the actors in the Comelico IA supply chain recognised the importance of energy security, by ensuring the regular provision of cheap pellets and fuelwood, and the use of owned and local resources, which is consistent with the findings of Schelhas et al. [94]. In fact, two hotel managers recognised that a combination of fragmentation of demand for biomass for energy and the increase in the price of biomass products for energy (e.g. fuelwood, woodchips, and pellets) made it difficult to obtain timely and quality supply from suppliers outside of Comelico, IA. Hotel managers reported fragmentation of demand (W7FC; Fig. 5) due to a low number of hospitality infrastructures and few contacts. One of them mentioned an attempt to create a buying group, since biomass suppliers prioritise large supply orders. This aspect is addressed in Strategy 3 (Section 5), through the organisation of a buying group.

It should be noted that the prices and supply security of biomass are not the only drivers of biomass fuel consumption. The willingness to pay for energy can be influenced by the renewable energy source, the ability to participate in the supply chain, the transparency of the price, and the proximity of the cooperative company that produces energy [95]. Across different supply chain actors, from forest companies to government officials and environmental NGOs, a strength of biomass use for energy is the reduction of greenhouse gas emissions [96]. Some final private users valued the use of local biomass for heating due to personal environmental sensitivity and the promotion of their activity as sustainable (S4FC, Fig. 5). The sustainability of using locally sourced fuelwood was used for both marketing their activities and personal satisfaction with using a local, renewable and clean energy source. However, they did not comment on the possibility of paying higher prices.

In addition to human-related external drivers, natural ones can also be drivers or barriers. The effects of natural disturbances in forests, such as the Vaia storm, have been considered, at the same time, a strength (S7I, Fig. 5) and a weakness (W3FC, Fig. 5) to the availability of biomass supplies. On the one hand, the high availability of biomass after disturbance was considered to be positive for the development of the supply chain. However, its impacts on provisions were considered current weaknesses and potential future threats, causing disruptions in supply and requiring adjustments of timber provision and management plans by the forest commons. Disturbances, such as the Vaia storm, are forces to consider when developing a biomass supply chain. Natural disturbances impact forest harvests by reducing harvest areas [97,98], and an increase in the frequency of such events is expected [99]. Disturbances cause large amounts of timber to enter the market at the same time, often affecting the forecasting of forest management plan provisions and forcing forest owners to change their harvesting plans. A potential advantage is that the Ukrainian war, the pandemic, and Vaia affected the Comelico IA population homogeneously, causing them to align on possible counteractions.

4.2.4. The role of logistics

Finally, logistics barriers were mentioned. Although these barriers, which are widely discussed in the literature, for example [100–102], were not the focus of the current study, we reported them for completeness. Logistic barriers (W13FC; Fig. 5) were reported primarily by final consumers, in terms of storage areas, when asked whether they would prefer to have an individual heating device, such as a boiler (DH), or to be connected to a district heating system (DHS). The high logistics costs of building infrastructure in the mountains were also mentioned by a mayor as a barrier.

4.2.5. The importance of a collective action approach

In general, many of the barriers and drivers that were presented can be overcome or capitalised on through a collective action approach. It was recognised that the individual Regole could not build a supply chain based only on the production of individual forest residues. Collective action between supply chain actors is considered a fundamental step in building support for the use of biomass as an energy resource [82]. The cooperation process is a key step for effective collective action and can include the transfer of knowledge and experience of the network, the joint purchase and provision of services, the production of physical energy, and exchange. Cooperation is said to be desirable for economic benefits and should be superior to actions carried out internally [103]. In the case of farmers, the establishment of a biomass power plant can be influenced by the decision of the farmers themselves on collective investment, which, in turn, is preferred by i) a low number of participants, ii) the short distance between the property and the power plant, and iii) specific contractual characteristics [104]. In fact, collective action between Regole, but also between final consumers, was considered positive for developing a forest residue-based supply chain (S5S; Fig. 5).

However, in practice collective action emergence was hindered by local rivalries, traditional individualism, historical conflicts (W9S, W10S, W11S; Fig. 5) and the lack of an active action arena, such as a recognised and shared space, in which to engage in collaborative initiatives.

Local rivalries between suppliers, the Regole, result in limited trust in renouncing control on the property over a consortium. There has been a general lack of trust due to past disappointment and the failure of collective action. Conflicts at the local level can prevent effective collective action. Conflicts generated by local rivalries were also found in Dautzenberg et al. [83]. Traditional individualism also causes general distrust and discouragement among locals, and these factors are consistent with Ostrom et al. [105] about the need for reciprocity and trust for collective action to happen. Cooperativeness also means giving up part of the managerial freedom [83], which is not seen favourably by most Regole presidents.

An opportunity to overcome local rivalries and individualism is presented by capitalising on forms of social homogeneity, such as social norms, according to which it is desirable, both from suppliers and final consumers, to see the forest clean from residues, felled trees, and so on (S6FC, S4S, S6S, Fig. 5). Kerr et al. [106] observed how social norms can effectively induce collective actions. Furthermore, Cembalo et al. [107] showed how social norms emerged as a key factor in helping to reduce free-riding issues by ensuring reciprocity and trust. Social norms are unconditional or, if conditional, not future-orientated and must be shared by other people and at least in part supported by their approval and disapproval [108]. Social norms can be derived from a common background and history, such as in the case of Comelico IA between different supply chain actors, primarily Regole (S6S, Fig. 5). This social homogeneity is expressed by the common background and knowledge of land and forest management. Furthermore, among final consumers, a B&B manager observed: 'There is a mental predisposition to keep the forest clean'. The same manager also said: 'By creating a cooperative of 20–30 people collecting forest residues, you create employment for locals and maintain clean forests'. Respondents mentioned the desire to keep the forest clean of residues, therefore granting recreational access to the forest, for themselves and others, and possibly providing a service to downstream communities in terms of preventing hydrogeological instability. It is generally acknowledged that focussing on the provision of an ecosystem service can have several effects on other ecosystem services [109,110]. In fact, we observed that there may be positive effects derived from the management of a specific ecosystem service, such as biomass for energy, which improves the accessibility and aesthetics of forests for outdoor recreation, as some of the final consumers mentioned, and when using them as an energy source and possibly improves the hydrogeological stability.

Another opportunity was technological innovation, such as new domestic stove models for wood chips (O3I, Fig. 5). Technological innovation can lead to collective action to distribute knowledge about a new technology among supply chain actors [111,112]. However, there are cases where technological innovation can also prevent collective action processes, e.g. Refs. [13,113].

Based on our results, we suggest strategies and actions supported by the literature or local policies to overcome barriers to supply chain development. We based the strategies on cooperation initiatives, primarily at the local level.

Table 3
Possible strategies that emerged from the SWOT analysis.

	Strengths	Weaknesses
Threats	***Strategy 1*** *S2I-S7FC-S6S – T6S- T1I – T7FC* Round table to prepare a list of demands for regional policy makers to improve bureaucratic procedures for the use and processing of this byproduct (wood chips from forest residues). Coordination with the regional forest enterprise consortium is recommended.	***Strategy 2*** *W2FC-W8FC-W4FC-W8I-W6S – T5S-T1S-T8FC-T10*FC Appropriate and sound communication on forest residue supply chain issues, providing examples of positive cases related to the weaknesses and threats mentioned.
Opportunities	***Strategy 3*** *S1S-S1I – O3FC-O4I-O2S* Organize a buying group for biomass (woodchips, pellets, and firewood) for final consumers in the hospitality sector managed by the tourism consortium for a membership quota.	***Strategy 4*** *W6S-W8FC – O5S-O4I-O3FC* Training courses for Regole administrators with both theoretical materials to be used and to support administrators and practical activities (field trips) to have first sight of positive examples.

Note: For each strategy, the source SWOT components are listed (e.g., S2I-S7FC-S6S stands for Strengths 2, 7, and 6 for intermediaries, final consumers, and suppliers, respectively).

5. SWOT strategies

Four bases for the strategies emerged from the content of the SWOT matrix (Fig. 5). Generally, optimal strategies are developed to maximise strengths and opportunities and minimise weaknesses and threats [75]. However, there are many examples in the literature that include other combinations [31,114,115]. In our study, we conducted a strengths, weaknesses, opportunities, and threats analysis, and we discussed the most promising results with the president and a member of one of the Regole involved. We propose strategies based on cooperation between actors to overcome the current impasse in the development of the local supply chain (see Table 3).

5.1. Strategy 1: Strengths - threat (S2I-S7FC-S6S – T6S- T1I – T7FC)

A basis for a strategy could be to produce a list of demands for regional policy makers, to present at roundtable events, to improve documentation of the forest residue supply chain, and to support regional forest services. Local forest companies that work with forest residues are the most skilled actors in the current supply chain in terms of forest residue use and procedures, as are forest owners. For example, simplification of documentation requirements could reduce transaction costs related to bureaucracy and increase the appeal of forest residues to be valorised. Examples could be drawn from the South Tyrol province, bordering the Comelico IA, as reported by a forest company. Local forest companies should work with the regional Consortium for Forest Companies (CIFORT) to improve the scale of their demands and gain momentum. Cooperation between stakeholders in the sector to improve the strength of demands on public institutions has been supported in the literature [116].

5.2. Strategy 2: Weaknesses - threats (W2FC-W8FC-W4FC-W8I-W6S – T5S-T1S-T8FC-T10FC)

Lack of awareness of the supply chain, lack of interest among the local population, confusion about biomass for heating CO_2 emissions, lack of vision, and uncertainties about economic advantages linked to a biomass supply chain are coupled with fear of depleting the forest and the effects of climate change on forests. These weaknesses and threats can be addressed through effective communication about these issues by providing examples of positive cases related to the weaknesses and threats mentioned via collective field excursions for Regole administrators and other communication material and engagement activities for local communities. The fundamental role of communication in facilitating the joint development of bioenergy supply chains is highlighted by Gold [117].

5.3. Strategy 3: Strengths - opportunities (S1S-S1I – O3FC-O4I-O2S)

Organising a buying group for biomass from forest residues (e.g., wood chips) for final hospitality consumers managed by the Tourism Consortium for a membership quota could counter demand fragmentation and limited bargaining power. Currently, the Tourism Consortium offers discounted prices for gas tanks to its associates. Members of the consortium could sign multi-year contracts with a local company that provides wood chips (and pellets) from local forest residues.

A similar approach could be adopted from the perspective of suppliers in organising the supply of biomass from forest residues. Rural Development Programmes (RDPs) directly supported the supply chains of biomass for energy. Other supporting legal instruments for Italian forest owners and intermediaries include Forest Agreements (Law Decree N° 77/2021), which are simple and flexible contracts between actors of the forest supply chain [118]; or LEADER cooperation (art. 34, Reg. (UE) 2021/1060).

5.4. Strategy 4: Weaknesses - opportunities (W6S-W8FC – O5S-O4I-O3FC)

To explore positive examples, training courses for Regole administrators with both theoretical materials to be used and to support administrators with no background in economics and forestry, and practical activities, such as field trips, are needed. The focus of training material should be on the production, collection, transformation, sale, and consumption of forest residues. The current perceived lack of vision and awareness may be related to a lack of formal training in the management of forest property and the availability of price information. This strategy is also supported by the literature [119–121]. A potential strategy to address the lack of professional training and to encourage a vision for the future could be based on professional training material. This training material could be supported by using RDP funding and collaboration with the university. Regole have liquidity (S3S) to use to finance the initiative or invest in applying to RDP incentives.

5.5. Limitations of the study

The main limitation of our study is the lack of prioritisation of SWOT factors. This limitation is especially evident, whereas a large number of factors are identified. This is a limit of SWOT analysis in general. A possible solution that could be implemented is the use of AHP and ANP methods [90,115,122], which allow quantitative prioritisation of factors through expert analysis. However, our main objectives were not to develop ranked factors for fully structured strategies, but rather to identify the factors for the development of the supply chain related to the social dimension. Therefore, we focus on the identification and comparison of factors with the international literature.

Our work is based on only one study area to suggest policy measures at the regional level. We accurately described the context to provide all the information needed to compare other areas with the Comelico IA. We also considered international literature to assess similarities and differences with a worldwide scope compared to the situation we analysed.

Another limitation of our study is due to the complexity of the forestry byproduct supply chain, which involves sectors and actors that are distant from each other. In many cases, the interests and expectations of these actors appear difficult to classify and compare. For this reason, national and local policies related to forest byproducts have often been difficult to define and implement.

6. Conclusions

The present study analyses the complexity of integrating multiple sectors and actors, from the forest sector to tourism and public administration, along with the power dynamics that govern a forest residue supply chain on a local scale. Many of the issues that arise are related to the product supplied, which in this case are forest residues with their specificities. Comelico IA is used as an example where, despite the stated abundance of forest residues, there is no local supply chain for the benefit of the local economy and welfare.

Our aim was to identify drivers and barriers, with a focus on the social dimension, that can hinder the development of the local supply chain for forest residues on a local scale in a rural area. Second, based on the results, our objective was to suggest strategies to overcome obstacles in developing a local supply chain of forest residues. We used the SWOT analysis method to identify and classify the factors influencing the development of the local supply chain of forest residues. The identified factors were assigned to four SWOT categories: strengths, weaknesses, opportunities, and threats.

Although we found differences in drivers and barriers in our study area compared to those in the international literature, we also found many similarities that we highlighted in our discussion. In the case of Comelico IA, the main barrier appeared to be related to a lack of knowledge of the potential of forest residue management, which can be linked to other barriers, such as the lack of vision of the local administration on the use of biomass for heating and the lack of interest in the collective action of Regole. On the other hand, strong drivers can be the social homogeneity, also in terms of social norms, of the forest commons and final consumers, as well as the skilled forest companies in the area.

Beyond the methodological limitations mentioned above, a limit of this study lies in the integration of perspectives of distant actors in the supply chain. This approach can limit the development of shared strategies due to different interests and expectations about the use of forest residues and in general wood sector byproducts. This is a reported issue also for drafting local and national policies.

More work on forest residue supply chain barriers and drivers in other cultural contexts, but similar geographical areas, could allow a better evaluation of specific factors related to our context or common factors in rural areas of the Alps. Improvement of the methodology could include methods to quantitatively prioritise the SWOT factors that emerged from the current work. A regional perspective would be more advisable for such a process. Finally, the next step of the study would be to identify the contractual characteristics and policy requirements needed for a collective action process between the different groups of actors in the supply chain.

Our results can support the development of sound policies for biomass use by providing insight from the personal experiences of supply chain actors. It should be noted that social drivers and barriers are important in developing local supply chains for forest residues, but technological advances and logistics are still key issues in the profitable use of forest residues.

Ethics declaration

All participants gave their informed consent to participate in the study. Ethical approval was not required due to the low risk for participants in the study. The final results of the study, derived from interviews, are presented mostly as codes, short sentences, and few translated sentences that cannot be associate with a specific participant.

Data availability statement

Data for this study, which are recordings and transcripts of semi-structured interviews with supply chain actors, are not publicly available due to privacy concerns and the possible identification of participants.

CRediT authorship contribution statement

Giacomo Pagot: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Nicola Andrighetto:** Writing – review & editing, Validation, Supervision, Formal analysis, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Giacomo Pagot reports financial support was provided by Ministero dell'Università e della Ricerca, the European Social Fund, the European Regional Development Fund and the Development and Cohesion Fund. If there are other authors, they 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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