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Use of Participatory Processes in Wood Residue Management from a Circular Bioeconomy Perspective: An Approach Adopted in Italy

Alessandro Paletto ^{1,*} , Claudia Becagli ², Francesco Geri ³, Sandro Sacchelli ³ and Isabella De Meo ² 

¹ Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA), Research Centre for Forestry and Wood, P.zza Nicolini 1, 38123 Trento, Italy

² Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA), Research Centre for Agriculture and Environment, 50125 Firenze, Italy; claudia.becagli@crea.gov.it (C.B.); isabella.demeo@crea.gov.it (I.D.M.)

³ Department of Agriculture, Food, Environment and Forestry, Consorzio Interuniversitario Istituto Nazionale di Studi su Agribusiness e Sostenibilità, University of Florence, 50125 Firenze, Italy; geri.francesco@gmail.com (F.G.); sandro.sacchelli@unifi.it (S.S.)

* Correspondence: alessandro.paletto@crea.gov.it

Abstract: The circular bioeconomy is aimed at achieving sustainable development through high efficiency utilization and resource recycling, and through combining environmental, economic and social objectives. Although the implementation of circular bioeconomy principles is based on a bottom-up approach, the participatory process has often been neglected. To overcome this problem, the present study investigated a case-study with a three-step participatory process. The process aimed to evaluate a forest-wood supply chain with consideration of the circular bioeconomy principles. A set of indicators was identified and assessed by a pool of experts. Then the members of a forest-wood supply chain were consulted to implement the identified actions. Finally, a focus group was organized with key stakeholders to discuss critical issues and strategies for enhancing the forest-wood supply chain locally. The results show that the proposed set of indicators is a useful tool to evaluate the performance of the forest-wood supply chain considering the circular bioeconomy principles. The results of the participatory process and related indicators' assessment identified the main weaknesses of the forest-wood supply chain. The main strategies to develop the local forest-wood supply chain toward the circular bioeconomy principles were also defined with a participatory approach.

Keywords: European Union Green Deal; stakeholder involvement; public participation; bioeconomy indicators; bottom-up approach



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1. Introduction

Recently, the concept of circular bioeconomy has become crucial in the European Union (EU) Green Deal to achieve resource-efficient biomass use and to meet the global climate targets established by the Paris Agreement on climate change in 2015 [1].

The concept of circular bioeconomy appeared in the scientific literature in 2015 and spread rapidly in the following years in both the scientific community and among decision makers [2]. The circular bioeconomy does not substantially differ from the circular economy, but it emphasizes typical peculiarities of the bioeconomy such as the use of biotechnology and biomass in the production of goods, services and/or energy. In particular, the concept of circular bioeconomy includes both the use of woody biomass as a renewable energy source and a co-producer of many bio-based products in an advanced multi-process industrial plant, known as a biorefinery [3,4]. The circular bioeconomy is characterized by multiple environmental and economic benefits, but, as emphasized by Stegmann et al. [2], a bottom-up perspective of circular bioeconomy has been neglected in the international literature. The bottom-up approach is a participatory design which, in the present case, aims at involving

key stakeholders in the implementation of circular bioeconomy strategies at a national or local level. The main aspects relating to this participatory approach are the identification of the key stakeholders—those who play a crucial role in the implementation of a project, plan or action—and the way to involve them in the decision-making process. The strength of this kind of approach is that it obtains expert knowledge at the various stages of decision making, and designing programs and strategies. The bottom-up perspective is particularly relevant in a circular bioeconomy in this context because many key strategies depend on the cooperation of local members along and across different supply chains [5]. In fact, these need establishment of consciousness and strong foresight, cooperation, collective effort and connection between inter-chain stakeholders to reach sustainable socio-economic growth, environmental benefits and technological advances [2,6]. In light of these assumptions, there is no doubt that the circular bioeconomy requires the involvement of key stakeholder groups including [7,8]: the public authority, industry, academia, workers, and the public. According to Kalmykova et al. [9] many types of stakeholders can be involved at different levels in the application of circular economy principles: from the general vision (e.g., public authors, non-governmental organizations), to research and development (e.g., academia, companies) and to market implementation (e.g., companies, workers, consumers).

In the circular bioeconomy framework, the forest-based sector plays a key role, contributing more than 20% to the EU's bioeconomy sector and has accomplished many strategic objectives related to the sustainable management of natural resources [10,11]. In this context, to monitor and assess the development of the circular bioeconomy objectives and strategies, an important tool is utilized, the implementation of indicators, which is related to but different to the Goal Indicators of the UN Agenda 2030 [12]. Indicators present a starting point to monitor circular bioeconomy supply chains assessing various aspects of development, such as productivity, performance and efficiency [13]. At the regional and local level, the application of indicators is useful for supporting decision makers to find solutions for sustainable development and to solve problems relating to the transition towards a wood-based circular bioeconomy [14]. This transition affects different sectors and could produce economic, environmental and social benefits and risks [15]. Specifically, the social implications may influence the acceptance of the development of supply chains based on circular bioeconomy principles that require cooperation and networks [16]. To ensure the acceptance of ambitious solutions based on sustainability, a bottom-up approach should be adopted through participatory processes and the involvement of stakeholders in the implementation and selection of monitoring indicators [17].

Participatory processes not only allow the involvement of local stakeholders, but enable them to consider a broad variety of information from different perspectives, to promote exchange of knowledge, to cooperate on discussing problems and their solutions, and to make decisions that are both legitimate and sustainable [18,19]. Even with these fundamental characteristics, the aims of participation can vary with the historical period and with the socio-economic and geographical framework; and there is no current agreement on an appropriate participation process defined by a unique and rigorous procedure or on a fixed structure [20].

According to Dietz and Stern [21] the intensity of involvement of the stakeholders refers to the extent to and ways in which the public can express an opinion. This can be reduced to simple written letters or information brochures, or can be extended to a highly-intensive level of interaction. With the level of involvement, the influence that stakeholders have in the decision-making procedure is also considered [22]. The efforts of participatory processes to involve stakeholders can result in different levels of participation, ranging from mere tokenism to collaborative partnerships [23] or, according to Arnstein [24], from "manipulation" aimed at convincing participants of the excellence of a decision process, to direct "citizen control" of the process itself. In both extremes lie different approaches corresponding to the different levels of stakeholders' involvement [25].

The definition of the level of participation is extremely important because each level of participation corresponds to a different capacity to influence the decision-making pro-

cess [23]. Once the level of participation is established, there are different methodologies that can be used in the participatory process, based on the utilization of different techniques [26]. The selection of a particular method or technique cannot be decided a priori but is a context-based choice, deeply related to the objectives of the specific process.

On the basis of the above mentioned considerations the objective of the present research is to develop a set of indicators suitable for evaluating the performance of the forest-wood supply chain with consideration of the circular bioeconomy principles. The novelty of the study is to have identified and tested indicators that combine the bioeconomy with the circular economy principles. Currently, most studies focus on separate indicators related to one of the two concepts: bioeconomy or circular economy. Furthermore, most of the indicators are not specifically identified for the forest-based sector. To overcome this knowledge gap, the present study integrates the two concepts to realize a single set of indicators. In addition, this study focuses on one of the crucial aspects of the circular bioeconomy applied to the forest-wood chain: wood-residue management in accordance with the “cascade principle” [27,28] as defined by the revised Renewable Energy Directive 2018/2001/EU (Renewable Energy—Recast to 2030). A bottom-up approach is adopted in this study, through consultation with affected stakeholders to ensure networking and cooperation between the various members of the sector.

2. Materials and Methods

The participatory process aimed to assess a forest-based sector according to the principles of circular bioeconomy was structured in three steps (Table 1):

- Involvement of a pool of experts to evaluate the performance indicators of the forest-wood supply chain from a circular bioeconomy perspective (September–October 2020);
- Consultation with the members of the forest-wood supply chain (private and public forest owners; forest enterprises; first and second wood processing enterprises; biomass energy plants) to provide data to assess the performance of the forest-wood supply chain in the pilot area (November 2020–August 2021);
- A focus group with the stakeholders to define the circular bioeconomy strategies aimed at improving the environmental and economic performance of the forest-wood supply chain (October 2021).

Table 1. Level of involvement and adopted technique for different groups in the participatory process.

Step	Group	Level of Involvement	Participatory Technique
1	Experts from the forest-based and bioenergy sectors	Consultation	Structured questionnaire—administered online
2	Members of the forest-wood chain	Information and consultation	Semi-structured questionnaire—administered face-to-face
3	Key stakeholders	Consultation	Focus group

2.1. Step 1—Expert Involvement

In the first step, a pool of experts from the forest-based and bioenergy sectors evaluated the suitability of ten indicators for assessing the performance of the forest-wood supply chain on three key criteria. The list of indicators used for this purpose is shown in Table 2. The selected indicators relate to several aspects of the forest-based sector and therefore have different units of measurement. These indicators were developed for use in the Multiple-Criteria Decision Analysis (MCDA) approach which is aimed at solving complex problems. According to the MCDA approach the selected indicators can be stated with different units of measurement. The criteria used to assess the indicators were selected based on the outputs of Gallego Carrera and Mack [29], and Dale et al. [30] and were adapted to the forest-based sector. The criteria used to assess the indicators can be thus summarized as:

- Efficiency: to improve the efficient use of resources and the circular economy, and to increase energy efficiency and renewable energy production;
- Applicability: to the forest-wood supply chain at a local level;
- Replicability: to other forest contexts both at a local and regional level.

Table 2. Indicators to assess the performance of the forest-wood supply chain considering the 4R framework of the circular bioeconomy.

4R	Indicator
Reduce	I ₁ —Ratio between annual value and annual mean harvested volume ($\text{€ q}^{-1} \text{ yr}^{-1}$)
	I ₂ —CO ₂ emissions per unit of wood product (tCO_2/m^3)
	I ₃ —Short supply chain: distance between sawmills and forests; distance between first and second wood processing companies (carpentry and joinery) (Km)
Reuse	I ₄ —Life span of the wood products (years)
	I ₅ —Wood products reused by the second wood processing enterprises (% of enterprises in the forest-wood chain)
Recycle	I ₆ —Ratio between the real economic value of the wood assortment and the potential value earned ($\text{€}/\text{€}$)
	I ₇ —Percentage of wood waste used in high value supply chains (%)
Recover	I ₈ —Wood residue used for bioenergy production (% of total wood residue produced by the forest-wood chain)
	I ₉ —Amount of roundwood recovered from infrastructures and products converted into bioenergy (m^3)
	I ₁₀ —Amount of CO ₂ emissions saved per unit of energy produced by wood residue ($\text{gCO}_2 \text{ kW}/\text{h}$)

In addition, the indicators were selected to take into account the three pillars of sustainability: environmental, economic and social. Some selected indicators refer to environmental sustainability (such as I₂, I₃, I₄, I₅, I₁₀), while others refer to socio-economic sustainability (such as I₁, I₆, I₇, I₈, I₉). Therefore, the set of indicators consider both the 4R framework and the three pillars of sustainability.

In September 2020, a web-based questionnaire was developed using the Google spreadsheet tool to support speed and timely processing of the gathering of the data. The pre-test phase was developed by six experts, identified from among academics and representatives of the public administration, in contact with and nearby the researchers involved in the present research. The aim of the pre-test stage was to verify the understandability of all items, to highlight complex and misguided questions and to estimate the completion time. At the end of the pre-test stage, the final version of the questionnaire was composed of sixteen questions structured in two sections. The following personal information was collected in the first section: age, employment sector, name of organization/institution, role in the organization/institution, years of experience in the forest-based or bioenergy sectors. The second section was composed of ten questions, one question for each indicator with a final open-ended question to collect additional potential indicators. In each question, the respondents were asked to assess each indicator on the basis of the three aforementioned criteria (efficiency, applicability, replicability), and to use a five point Likert scale format (from 1 = very low importance to 5 = very high importance). In October–November 2020, the experts were invited by phone to participate in the survey. Subsequently, the final version of the questionnaire was sent by email to 56 experts from the forest-based and bioenergy sectors. The experts were identified by researchers and local partners in a brainstorming session. The criteria for expert selection utilized during the brainstorming session were those described by Grilli et al. [31]: (1) expertise and skills in forest and bioenergy sectors at a national or regional level; (2) no direct stake in the development of the Valdarno–Valdisieve forest-wood supply chain. The experts were selected from three categories of institutions and organizations: public administration, private companies and freelancers. After a waiting period of one month and with a reminder sent 14 days after the first email, 30 experts filled out the questionnaire (response rate of 53.6%). The respondents were distributed by category: eight freelancers, eleven representatives of public administrations and eleven representatives of private companies. The response rate found in this survey was satisfactory because it was higher than those evidenced by Prasad Nayak and Narayan for different kinds of surveys [32]. They showed a response rate of 30% in email surveys,

29% in online surveys and 13% in surveys delivered within an app. The collected data were used to put the indicators into a hierarchy of importance within the 4R framework.

2.2. Step 2—Consultation with Forest-Wood Supply Chain Members

Among the various levels of participation, consultation is characterized by the fact that involved stakeholders are first informed and then their opinions and interests are heard by decision makers [33]. No guarantee is given that the requests of the stakeholders affect the final decision. However, feedback is provided regarding the level of acknowledgement and inclusion of stakeholders' expectations in the decision-making process [34]. During the second step of the participatory process, all members of the forest-wood supply chain operating in the Valdarno–Valdisieve (Tuscany, Central Italy) were identified starting with the official list of forest and wood processing enterprises registered in the bulletin of the Chamber of Commerce Industry Handicraft and Agriculture (CCIHA). The list of forest and wood processing enterprises was integrated through a snowball sampling method [35], which is a non-probability sampling technique where initial respondents provide key information regarding subsequent respondents. In this non-random sampling technique, the initial participants, identified from the official list of the CCIHA, provided names of other members of the forest-wood supply chain that could potentially be involved in the survey on the basis of their knowledge of the local context. In this study, the additional members of the forest-wood supply chain in the pilot area were provided by the respondents who filled out the semi-structured questionnaire. At the end of this phase, 28 members of the forest-wood supply chain in the Valdarno–Valdisieve were identified, who belonged to the following groups: seven forest owners and enterprises, four first wood processing enterprises, eleven second wood processing enterprises, six Heating District Plants (HDPs) and Combined Heat and Power Plants (CHPs). Therefore, all categories of forest workers were included in this step of the study. In November 2020, a preliminary version of the questionnaires for each group were developed and pre-tested with four members of forest-wood supply chain located outside the pilot area. The information collected with the questionnaires administered to the four groups is summarized in Table 3.

In the period between December 2020 and August 2021, the final versions of the questionnaires were administered face-to-face with the members of the forest-wood supply chain in the Valdarno–Valdisieve. The collected data were used to calculate the ten aforementioned indicators.

2.3. Step 3—Focus Group with All Stakeholders

Focus groups are defined as an in-depth interview delivered in a group. The discussions have different characteristics based on the size and composition of the group, and the interview procedures [36]. In a focus group, a moderator stimulates discussion and debate on a topic, while the participants influence each other with their contributions during the meeting [37]. According to Balest et al. [38], the role of the moderator should be assigned to an external person who is not affected by the issue being discussed, for reasons of transparency and independency. A focus group was organized in November 2021 to discuss the critical issues of the forest-wood supply chain at a local level and to find shared strategies to enhance the forest-wood supply chain. For this reason, a preliminary stakeholder analysis was conducted which aimed to identify all groups of people, organized or informal, who had a stake in a particular issue, their interests, the conflicts of interests between different stakeholders, and the possible “coalitions” [39]. The stakeholder analysis procedure proposed by Grilli et al. [40] and Pelyukh et al. [41] was implemented to identify the key, primary and secondary stakeholders. At the end of the stakeholder analysis, all identified key stakeholders were invited to participate in the focus group. During the focus group, held on 10 November 2021, in the Valdarno–Valdisieve area, 25 stakeholders (approximately 40% of the stakeholders invited) participated under the coordination of a facilitator external to the study area, but with expertise in the forest sector. The focus group was organized in two phases. In the first phase, the participants identified the main

weaknesses of the forest-wood supply chain of the Valdarno–Valdisieve that the facilitator had arranged as a “Problem Tree”. The aim of the “Problem Tree” is to identify a core problem and its causes and consequences according to the logic, values and consensus of stakeholders [42]. In the second phase, the participants transformed the “Problem Tree” into a “Strategy Tree” for improving the performance of the forest-wood supply chain in accordance with the principles of a circular bioeconomy. For each “branch” of weakness, a strategy was defined by the stakeholders to overcome the weakness. Each step involved a different group of participants and a different participatory technique was applied (Table 1). In the first step, the experts were involved using a web-based questionnaire; in the second step, the members of forest-wood supply chain were first informed and then consulted using a semi-structured questionnaire; in the third step, the key stakeholders were engaged in a focus group aimed at identifying strategies for the enhancement of the forest-wood supply chain in the pilot area (Valdarno–Valdisieve). The data collected during the focus group was recorded and processed using NVivo 11 Pro software. The keyword analysis performed with the software highlighted the main weaknesses of the forest-wood supply chain. In addition, the main weaknesses were ranked by importance based on the frequency with which each keyword was mentioned by the focus group participants.

Table 3. Data collected with the questionnaires administered to each group from the forest-wood supply chain.

Group	Data Collected
Forest owners and enterprises	<ul style="list-style-type: none"> – Name, location, ownership – Number of part-time and full-time employees – Annual tree species harvested – Location and annual amount of wood harvested and destination – Annual amount of woodchip produced and destination – Productivity and machinery used in forest interventions
First wood processing enterprises	<ul style="list-style-type: none"> – Name, location, ownership – Number of part-time and full-time employees – Annual tree species processed – Origin and annual amount of timber processed – Annual amount of wood residue produced and destination – Annual amount of finished and semi-finished product and destination
Second wood processing enterprises	<ul style="list-style-type: none"> – Name, location, ownership – Number of part-time and full-time employees – Annual tree species processed – Origin and annual amount of semi-finished wood products processed – Annual amount of wood residue produced and destination – Annual amount of final product and destination
Biomass energy plants	<ul style="list-style-type: none"> – Name, location, ownership – Number of part-time and full-time employees – Starting year, net length, working hours – Energy produced and sold, self-consumption of energy, pollutant emissions, ash yield and disposal technique – Feedstock characteristics (origin, amount, moisture, pre-treatment)

3. Results

3.1. Step 1—Expert Involvement

The results identified that in the first step of the process of participation, for the pool of experts, the most important indicator in the “Reduce” group was the ratio between annual value and annual volume harvested (I_1), with an average value of the three criteria equal to

3.46; followed by the short supply chain (I_3) with an average value of 3.37. In the “Reuse” group, in accordance with the experts’ opinions, the most important indicator was the time of use of products (I_4) with an average value of 3.22; while for the “Recycle” group, the indicator I_6 (ratio between the real economic value of the wood assortment and the potential value) was considered the most important indicator, with an average value of 3.14. In the “Recover” group, two indicators are considered equally the most important by experts: the percentage of wood waste for bioenergy production (I_8) with an average value of 3.78, and the amount of carbon dioxide (CO_2) emissions saved per unit of energy produced by the wood wastes (I_{10}) with an average value of 3.61.

The results for each criterion and for all indicators are shown in Table 4, while a box-plot of global mean values for each indicator is shown in Figure 1. Furthermore, the non-parametric Kruskal–Wallis test was applied to test whether there were statistically significant differences between the three groups of respondents (public administration, private companies, freelancers) for each indicator. This non-parametric test was used rather than parametric tests because the sample size was small and no normal distribution was observed. Comparing the opinions of the three categories of institutions and organizations showed some differences. With regard to the “Reduce” group, the representatives of public administrations assigned a higher value to indicators I_1 (mean value 3.70) and I_3 (3.82) compared to the other categories, while for indicator I_2 the highest value was assigned by the representatives of private organizations (3.06). For the two indicators of the “Reuse” group, the results showed that for I_4 the highest value was assigned by the representatives of the public administrations (3.49), and for I_5 by the representatives of private organizations (3.06). Concerning the “Recycle” group, for both indicators the highest values were assigned by representatives of the public administrations ($I_6 = 3.39$, $I_7 = 2.55$) and by those of private organizations ($I_6 = 3.36$, $I_7 = 2.58$) with similar mean values. Finally, for the last group (“Recover”), the importance of two indicators was especially emphasized by representatives of private organizations ($I_8 = 4.06$ and $I_{10} = 4.00$), while the importance of indicator I_9 was emphasized by the freelancers (2.71) compared to the other two categories (mean value of 2.21 for private organizations and 2.61 for public administrations). However, the results of the non-parametric Kruskal–Wallis test ($\alpha = 0.01$) show no statistically significant differences between the three groups of respondents for all ten indicators (p -value from 0.907 for I_8 and 0.035 for I_6).

Table 4. Level of importance of indicators to assess the forest-based circular bioeconomy in accordance with expert opinion (mean and standard deviation).

R	Indicator	Efficiency ($n = 30$)	Applicability ($n = 30$)	Replicability ($n = 30$)
Reduce	I1	3.87 ± 1.17	3.27 ± 1.26	3.23 ± 1.28
	I2	3.27 ± 1.34	2.50 ± 1.07	2.60 ± 1.13
	I3	3.80 ± 1.24	3.13 ± 1.33	3.17 ± 1.32
Reuse	I4	3.60 ± 1.33	3.07 ± 1.28	3.00 ± 1.26
	I5	3.23 ± 1.41	2.50 ± 1.22	2.70 ± 1.37
Recycle	I6	3.37 ± 1.56	3.10 ± 1.27	2.97 ± 1.33
	I7	3.00 ± 1.51	2.40 ± 1.22	2.23 ± 1.28
Recover	I8	3.87 ± 1.31	3.67 ± 1.30	3.80 ± 1.27
	I9	2.83 ± 1.26	2.30 ± 1.21	2.33 ± 1.37
	I10	3.73 ± 1.53	3.63 ± 1.47	3.47 ± 1.43

The non-parametric Kruskal–Wallis test was also applied to identify if there were statistically significant differences between the four groups of R of the circular bioeconomy. The results of the test showed a statistically significant difference between the four groups for two criteria: applicability ($\alpha = 0.01$, $p = 0.007$) and replicability ($\alpha = 0.01$, $p = 0.03$), but not for efficiency ($\alpha = 0.01$, $p = 0.086$).

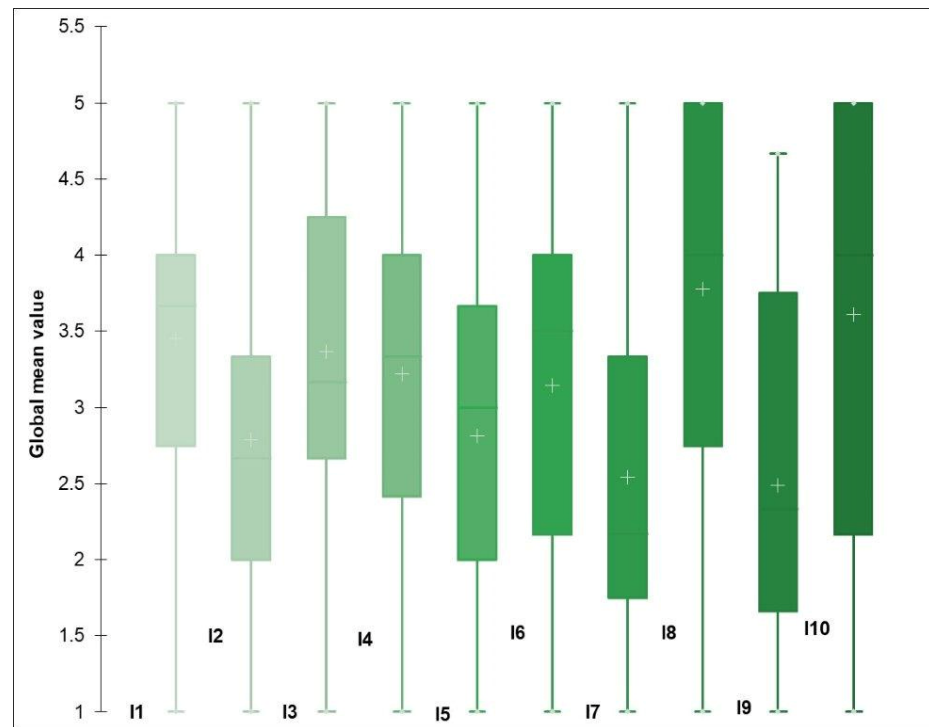


Figure 1. Box-plot of global mean values for each indicator used to assess the forest-based circular bioeconomy.

The hierarchical position of the indicators in the 4R framework is shown in Figure 2. As emphasized by Van Buren et al. [43], the hierarchy of the R is fundamental to the 4R framework to reach the goals of the circular bioeconomy. The hierarchical relationship among the four Rs is closely linked to the rational use of raw materials [44] and the “cascade” principle which indicates the usage of raw materials according to a priority based on the added potential [27].

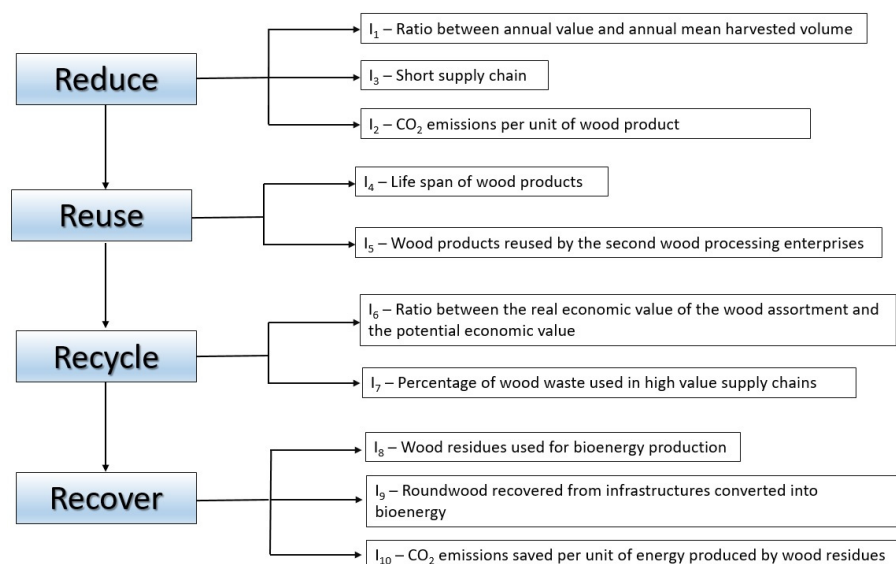


Figure 2. Hierarchical position of ten indicators in the 4R framework as rated by experts.

3.2. Step 2—Consultation of Forest-Wood Supply Chain Members

In the second step, the previously identified indicators were calculated based on the data provided by the members of the forest-wood supply chain in the Valdarno–Valdisieva area.

3.2.1. Reduce

The first indicator in the “Reduce” group (I_1) highlighted that the forest-wood supply chain of the Valdarno–Valdisieve had a ratio, between annual value and annual harvested volume, equal to $\text{€}66.5 \text{ t}^{-1}$. In particular, the five forest enterprises harvest 5810 t, on average, annually of fuelwood and $12,340 \text{ m}^3$ of roundwood with a total economic value of $\text{€}616,623$. This economic value was due to the fact that almost all roundwood volume is used for packaging production with market prices of $\text{€}6 \text{ q}^{-1}$ for Douglas fir (*Pseudotsuga menziesii*), $\text{€}8 \text{ q}^{-1}$ for silver fir (*Abies alba*) and $\text{€}3.1 \text{ q}^{-1}$ for black pine (*Pinus nigra*), while the average market price of fuelwood was $\text{€}7.0 \text{ q}^{-1}$.

The second indicator (I_2) regarding carbon dioxide (CO_2) emissions during silvicultural operations was estimated for four phases: felling, harvesting, chipping and transport. Roundwood and woodchips were considered separately. Considering the average productivity for each phase and the quantity of wood materials annually harvested (Table 5), the results show that the CO_2 emissions for the production of one ton of wood material is equal to 12.38 kg CO_2 . The contribution of each phase was: 8.0% for felling, 41.0% for harvesting, 42.4% for chipping and 8.6% for transport.

Table 5. Average productivity, consumption and carbon dioxide emissions in the forest-wood supply chain phases.

Phase	Quantity (t year^{-1})	Average Productivity (t h^{-1})	Fuel Consumption ¹ (L/h or km/L)	Carbon Dioxide Emissions ² (tCO_2)	Carbon Dioxide Emissions per Unit ($\text{kgCO}_2 \text{ t}^{-1}$)
Felling	9358	1.6	0.6	9.3	0.99
Harvesting	9358	2.4	4.6	47.5	5.08
Chipping	1000	10.1	20.0	5.2	5.25
Transport woodchips	1000	20.0	4.9	0.37	0.37
Transport roundwood	8358	20.0	4.9	5.75	0.69

¹ For felling, harvesting and chipping phases, the gasoline consumption is in litre/hour of work, while for the transport phase the consumption is in km/litre. ² Carbon dioxide (CO_2) emissions per litre of gasoline is $2.65 \text{ kgCO}_2/\text{L}$ [45,46].

The third indicator (I_3) showed that the average distance from the forest areas to the first wood processing enterprises was 14.0 km estimated using a Geographical Information System (GIS) approach, while the total distance travelled annually was equal to 10,637 km (round trip) to bring 8358 t of roundwood to the sawmills. Using the same approach, the average distance from forest areas to HDPs was 9.6 km corresponding to a total distance travelled annually of 686 km (round trip) to bring 1000 t of woodchips. It is interesting to note that for both types of wood product the principles of the short supply chain were respected (destination of raw material within less than 50 km).

3.2.2. Reuse

The “Reuse” was measured by the sum of the life span of the wood products reused one or many times before being transformed into energy. According to Anderle et al. [47], the life span of wood products is: 6 months for woodchips and pellets (including the wood drying time); 2 years for paper; 3 years for packaging (i.e., pallets); 10–30 years for furnishing; and 15–35 years for timber for building. In the present study, to estimate the global life span of the products of forest-wood supply chain, the wood products derived from first and second wood processing enterprises were considered. The results showed that the first wood processing enterprises produce 1416 m^3 of finished or semi-finished wood products annually, thus distributed by type of products: 68.9% for packing strips, 28.6% for sawn products, 1.8% for fuelwood, and 0.7% for battens for building. The second wood processing enterprises produce 107.5 m^3 of finished wood products annually (75.7% for furniture, 14.1% for higher fashion products, 5.4% for barrels for wine, 2.6%

for sandwich panels and 2.4% for building). Taking into account these data (Table 6), the average life span of all wood products (I_4) estimated considering the product quantity and the average life span of each type of product was 8.7 years, with differences between finished and semi-finished products: 8.0 years for semi-finished products and 18.5 years for finished products.

Table 6. Wood products produced by first and second wood processing enterprises in the study area with the average life span.

Wood Products	Quantity Produced (m ³)	Average Life Span (Years)
	First wood processing enterprise	
Sawn products	405.0	20
Packing strips	975.0	3
Battens for building	10.0	25
Fuel wood	26.0	0.5
	Second wood processing enterprise	
Finished product for furniture	83.4	20
Finished product for higher fashion (bags)	15.5	10
Sandwich panels	2.6	10
Finished product for building	2.6	25
Barrels for wine	6.0	20

Regarding the potential reuse of wood products in forest-wood supply chain (I_5), the results showed that 4 of 11 s wood processing enterprises reuse roundwood recovered from infrastructures and artefacts (41.7% of total enterprises). These second wood processing enterprises use reclaimed roundwood to produce pallets, sawn products, doors and slats.

3.2.3. Recycle

The results of the first indicator of the “Recycle” group identified that the ratio between the real economic value and the potential economic value (I_6) was 0.8 due to the incomplete economic exploitation of the types wood products of two local species: Douglas fir (*Pseudotsuga menziesii*) and sweet chestnut (*Castanea sativa*). In other words, the Valdarno–Valdisieve forest-wood supply chain was at 80% of its potential for economic development of local wood production. It is important to note that I_6 was calculated considering the increase in the selling price of wood products in the potential scenario, while changes in production costs were not considered. Regarding Douglas fir, the results showed that all harvested volume was allocated for packaging production, while the best quality trees were allocated for beams and plywood production thanks to the strength-to-weight ratio of this species. Regarding the sweet chestnut, the results showed that only a minimal amount of the volume was allocated for pole production, which is the highest-paying wood product on the market. The current shortage of pole wood product is due to a previous forest management problem that led to the aging of chestnut-dominated forests.

Regarding the second indicator (I_7), according to the data provided by the enterprises interviewed, the percentage of wood residue used in high value supply chains was zero (0%). According to Tamantini et al. [48] and Paletto et al. [49] wood residue from forest-wood supply chain could be enhanced in “second-generation” refineries (2G). In particular, lignin from 2G biorefineries can be used to produce essential green value-added phenolics [48]. However, all wood residue produced by Valdarno–Valdisieve forest-wood supply chain are destined for traditional uses such bioenergy production, animal litter and panel production.

3.2.4. Recover

Concerning the groups of indicators of “Recover”, the results showed that almost all wood residue generated by silvicultural interventions are not removed by forest enterprises for ecological and technical-logistical reasons. First, it is important to point out that only one

of the five forest owners and enterprises had a woodchipper (annual woodchips production of 1000 t per year), while the other enterprises did not own nor rent a woodchipper. Secondly, the first wood processing enterprises produced a total of 361 t of wood residue per year (on average 90 tons of wood residue per year per enterprise), split according to the destination: 79.4% sold for energy production; 9.7% sold for animal litter; 5.8% sold for panel production; 3.7% gifts to farmers and the remaining 1.4% disposed as waste. Thirdly, the second wood processing enterprises produced a total of 21.5 t of wood residue per year (on average approximately 1.95 t per year per enterprise) thus distributed: 51.4% self-consumed in the same enterprise, 47.8% disposed of as waste, and the remaining 0.8% given away for free. Therefore, in the Valdarno–Valdisieve forest-wood supply chain a total amount of 1382.5 t of wood residue was produced annually (72.4% forest woodchip and 27.6% wood processing woodchip and sawdust), of which 93.1% was used for energy purposes (I_8).

Concerning I_9 (amount of roundwood recovered from infrastructure and products converted into bioenergy), the results showed that none of the enterprises interviewed recover roundwood from infrastructure and products to produce energy.

With regard to the indicator I_{10} , the data were processed considering that wood material be considered “carbon neutral” in the bioenergetic cycle. The carbon dioxide (CO_2) emissions due to the carbon content in the woody biomass (biogenic carbon) are generally neglected in the assessment of the combustion impact on the climate change [50]. I_{10} assessed the amount of CO_2 generated by the C biogenic based on the amount of wood material used for bioenergy production. This means that a certain amount of fossil fuels is saved when the wood is used for heating purposes. The results showed that the six HDPs located in the Valdarno–Valdisieve use 2618 t of forest woodchips annually (on average 436 t of woodchips per HDP) to produce 4778 MWh year⁻¹. Starting from the annual woodchip consumption of the six HDPs, the results showed that the use of woodchips rather than gasoline to produce the same quantity of thermal energy led to a saving of 1475 tCO₂ per year (Table 7).

Table 7. Carbon dioxide (CO_2) saved by the use of woodchips rather than gasoline.

	Woodchip	Gasoline
Lower Calorific Value (LCV)	3.4 MWh/t	11.6 MWh/t
Yield	0.54	0.85
Total energy consumed	8867 MWh	5505 MWh
Thermal energy produced ¹	4778 MWh	4778 MWh
Quantity	2618 t	475 t
Tons of oil equivalents	0 t	465 t
CO_2 emissions ²	0 tCO ₂	1475 tCO ₂

¹ 1 t of gasoline = 0.98 TEP. ² One liter of gasoline is 0.835 kg; 2.65 kg CO_2 emissions per liter of gasoline.

From a theoretical point of view, if all wood residue produced by Valdarno–Valdisieve forest-wood supply chain were allocated to energy production in local HDPs, this production would satisfy 53% of the total energy demand. Instead, currently only 38.3% of total energy demand is satisfied with local wood residue. This difference is due to the fact that a percentage of the wood residue produced by the wood processing enterprises is sold to HDPs and CHPs outside the study area.

3.3. Step 3—Focus Group with All Stakeholders

During the focus group, the results of the first two steps were shown to all stakeholders in order to start a debate about the weaknesses of the local forest-wood supply chain. At the end of the first part of the focus group, the stakeholders identified fourteen weaknesses that were then summarized into six groups of problems (branches of the “Problem Trees”—see Figure 3). The six group of problems were summarized as follows:

- Low level of entrepreneurship of local forest-wood supply chain operators and consequent difficulty in the diffusion of innovation (transformation of an idea into an innovation);
- Low level of trust between forest-wood supply chain operators and the public authority;
- Lack of knowledge and awareness of the potential of Chain of Custody (CoC) certification;
- Low competitiveness of local enterprises in the procurement of quality timber;
- Inability to communicate the environmental value of wood products to end consumers;
- Suboptimal ascribed value of wood residue.

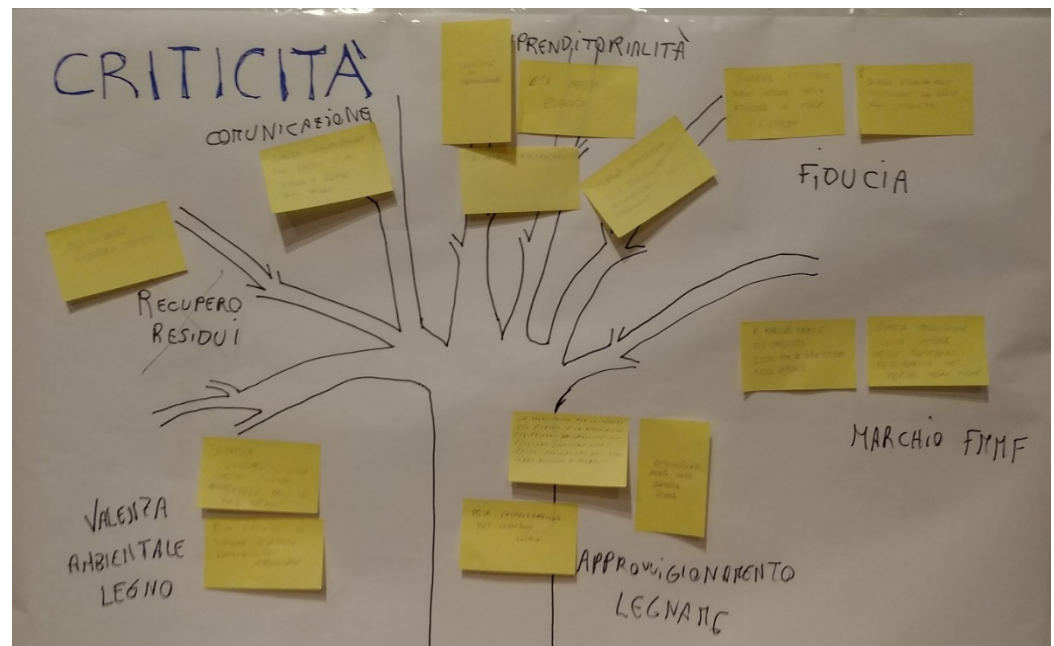


Figure 3. “Problem Trees” related to the weaknesses of the Valdarno–Valdisieve forest-wood supply chain.

In the second part of the focus group, the participants, with the support of the facilitators, identified the most suitable strategies to solve the aforementioned weaknesses of the Valdarno–Valdisieve forest-wood supply chain. It is important to emphasize that the identified strategies considered the participants’ level of knowledge and perception of the weaknesses. After a discussion of over 2 h moderated by the facilitator, the participants suggested the following shared strategies for the enhancement of the forest-wood supply chain from a circular bioeconomy perspective:

- Organize training courses for forest-wood supply chain operators giving particular regard to entrepreneurial and managerial skills;
- Encourage opportunities for joint collaboration between forest-wood supply chain operators and public authority in order to improve the relationship of mutual trust;
- Adopt a communication plan to increase the knowledge and awareness of the environmental value of wood products of end consumers;
- Invest in forest certification with particular reference to the Chain of Custody (CoC) and the local brand Montagne Fiorentine Model Forest (FMMF).
- Identify new and more profitable markets for the wood residue produced by the forest-wood supply chain (e.g., advanced biofuels, bio-textiles and bioplastics).

4. Discussion

The present study showed a possible participatory approach to the assessment of the forest-wood supply chain established on the principles of circular bioeconomy.

According to the Italian Bioeconomy Strategy (2017) and the National Strategy for Sustainable Development (2017) principles, the participatory process has been implemented at the local level through the involvement of different group of stakeholders. The partici-

partory method proposed in this study can be replicated in other local contexts. Therefore, the target audience of the study are mainly policy makers whose aim is to improve the efficiency of the forest-wood supply chain by following the principles of the bioeconomy and the circular economy. Local policy makers can replicate the participatory method used in the present study by adapting it to the context in their own territory. The results provided by the set of indicators applied to Valdarno–Valdisieve case study may be useful to local decision makers for identifying new strategies for enhancing the forest-wood supply chain in accordance with their stakeholders' opinions and expectations.

The key benefit of the described methodology is that it adopts differentiated involvement methods for different stakeholders within the forest sector: (1) in the first, more technical, phase, the experts were involved in validating the method used to assess the performance of forest-wood supply chain in accordance with the principles of circular bioeconomy; (2) in the second phase, the operators were consulted to investigate the performance of forest-wood supply chain; (3) in the third phase, all key institutional and non-institutional stakeholders were involved in a focus group that aimed to identify strategies for enhancing the forest-wood supply chain at a local level. The proposed method is based on the principles of the participatory approach and encourages participants to take responsibility, promotes participation for all, reconciles different interests and listens to the local community [51,52]. Contrariwise, the main disadvantage of this method is that it can be time consuming to carry out the whole participatory process, as established by Kaiser and Forsberg [53]. In agreement with this last point, the participatory process developed in this study took 14 months and the full-time involvement of two people. However, the participatory process activated a process of mutual listening and laid the foundation for future improvement of mutual trust between members of the forest-wood supply chain and the public authority. The role of the participatory process in increasing trust both horizontally (between entrepreneurs of the forest-wood supply chain) and vertically (between entrepreneurs of the forest-wood supply chain and the public authorities) has been emphasized by several authors [54–56].

The overall results of the participatory process highlight the weaknesses of the forest-wood supply chain both from a quantitative (implementation of the indicators) and qualitative (results of the focus group) point of view. First of all, the annual commercial value per unit of wood product is quite low (66.5 € t^{-1}) due to the main wood products: bioenergy and packaging production. The low quantity of valuable wood products also affects the average life span of finished and semi-finished products (8.7 years). A higher percentage of wood products such as sawn wood and wood-based panels could result in an average life span of over 20 years and a recycling percentage of 20% [57].

In addition, in the Valdarno–Valdisieve study area some important local species—i.e., Douglas fir and sweet chestnut—are not sufficiently valued from an economic point of view. To overcome these weaknesses, forest management practices applied in the chestnut-dominated forests should be changed with the aim of improving the coppice structure for the production of poles, while the larger sized Douglas fir products could be selected and destined for beams and plywood production rather than for packaging production.

Considering the CO₂ emissions during the silvicultural operations, the results show a global value of 12.38 kg CO₂ per ton of wood. This value is in line with that provided by Pieratti et al. [58] for another study area in Central Italy (11.62 kg CO₂ per ton of wood). In our study, the two phases that generated the greatest environmental impacts in terms of CO₂ emissions were: harvesting (41.0% of total CO₂ emissions) and chipping (42.4%). These environmental impacts are due to the low-medium level of mechanization of local forest enterprises and the high variability of the productivity of the wood chipping [59,60]. In addition, it is interesting to emphasize that the transport phase had low CO₂ emissions thanks to the use of the raw material, both roundwood and woodchips, locally. The use of raw material in a short supply chain is one of the strengths of Valdarno–Valdisieve because it reduces the environmental impact of the transport phase. According to Paletto et al. [49] and Klein et al. [59], the transport phase can be considered one of the most environmentally

impactful phases; therefore, the implementation of a short supply chain can improve the ascribed value of local wood and reduce climate impacts. The use of local woodchips for energy purposes has the advantage of saving on the emission of 1475 t CO₂ per year due to the use of renewable fuel rather than fossil fuels.

Two other possible strategies for economic valorization of the wood raw material are: (1) to increase the dissemination of knowledge related to the local Montagne Fiorentina Model Forest (FMMF); and (2) to increase the quantity of forest-wood residue taken from forests for bioenergy production of woodchips to meet local energy demand. In our opinion, the FMMF brand for wood traceability could be an interesting marketing tool with the potential to improve competitiveness and provide a premium price for local forest enterprises [60]. This is due to the global recognition of the brand in the International Model Forests Network (IMFN) and its ability to facilitate communication between the different members of the forest-wood supply chain, connecting supply and demand of several finished and semi-finished wood products [61]. Regarding the second potential strategy, a greater quantity of wood residue produced by silvicultural interventions should be removed and utilized to meet local energy demand. Currently, just over 10% of total potential wood residue is used for bioenergy production, while only 38.3% of the total energy demand is satisfied with local wood residue. Therefore, wood residue removed from forests could be increased through greater mechanization of local forest enterprises and the implementation of organizational and marketing eco-innovation [62]. Furthermore, it is important to highlight that the woody biomass from forests should be used according to its highest economic and environmental value as established by the Renewable Energy—Recast to 2030. In particular, woody biomass should be used according to the following order of priority: at the top, the production of wood-based products; and next, the extension of their service life; following there is reuse, recycling and bioenergy production; and the last is disposal. Also, the use of sawlogs, veneer logs, stumps, and roots to produce energy should be avoided.

5. Conclusions

The overall results of the participatory process highlight the lack of progress of the forest-wood supply chain according to the circular bioeconomy principles, both quantitatively and qualitatively. Nevertheless, the assessment framework (online questionnaire, interview survey, focus group) proved useful in producing a multi-stakeholder perspective, including researchers, public authorities, private companies and others. This approach was useful to expand the knowledge of circular bioeconomy principles and practices among the members of the forest-wood supply chain and to go beyond the current early stage.

It is important to note, in light of the success of the participatory process, that new participatory approaches must be devised. The participatory process which was developed and tested proved to be useful for the enhancement of the forest-wood supply chain under the circular bioeconomy principles. One crucial characteristic to mention is the trust developed between research group and stakeholders of the sector during the participatory process. The use of questionnaires and of standardized templates for communicating information was useful. In fact, it avoided the occasional absence of interaction due to process-level disparities between the various stakeholders of the forest-wood supply chain. Furthermore, particular attention was paid to the inclusiveness of the process. In this sense, an effort was made to give voice to all those members who generally have a marginal role in the decision making but whose role in the forest-wood supply chain is very important.

Finally, it is important to stress the adaptability of the participatory procedure to different socioeconomic contexts. There is a wide range of possible techniques and methods. The public participation approach is not based on a fixed structure and the selection of a specific method cannot be decided a priori. Anyhow, all phases of the participation process must be characterized by a continuous flow of information between policy makers, managers, practitioners and other stakeholders.

The involvement of the forest sector's stakeholders in the indicator choice and assessment procedure was essential in guaranteeing the involvement of a broad range of societal values and opinions. This ensured that performance indicators were not simply built in the domain of experts but were additionally accepted by different stakeholders. Thus, the acceptance and usefulness of the performance indicators were put on firm footing.

Finally, it is important to highlight some aspects that support development towards circular bioeconomy. These include fostering the dissemination of the local brand through territorial marketing for wood traceability; facilitating cooperation between stakeholders along forest-wood supply chain; intensifying, through silvicultural practices, forest management choices or mechanization operations; the use of wood residue to meet local energy demand; and finally, to increase the supply of wood products with increased durability, reuse, recycling and biodegradability.

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