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Circular Economy Model: Insights from a Case Study in South Italy

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Abstract: This study aims to analyze the economic and environmental sustainability of a case study of an energy power plant that produces electricity from pruning residues of olive groves from nine municipalities in southern Italy. To assess the economic sustainability of the agro-energetic chain, the profitability and efficiency ratios are calculated. Moreover, the GHG emissions of the agro-energetic pruning supply chain due to both the pruning collection at the field level, and their combustion for energy production at the power plant, are calculated. To put together the environmental and economic evaluations, the ecoefficiency ratio was calculated to measure the value added per 1Mg of GHG emitted into the atmosphere. The findings show the whole agro-energetic chain, namely the power plant and the collection company have both a good return on owner's equity (ROE) ratio (15.89% and 31.48%, respectively) and ROI ratio (4.34% and 6.14% respectively). Moreover, the power plant's ecoefficiency ratio (2.64€ per 1Mg of GHG) is slightly lower than harvest firm one (2.91€ per 1Mg of GHG). The findings could be useful to develop new business models based on the circular economy concept. In fact, the business model proposed could push entrepreneurs towards new income opportunities, at the same time, helping local farms and reducing the environmental impacts.

Keywords: new business model; ROI; ROE; GHG emissions; ecoefficiency ratio; olive groves; pruning biomass; circular economy

1. Introduction

Concerns about emissions from fossil fuel use have stimulated renewable energy adoption, which included bioenergy and its crop residue [1]. Among crop residues, prunings have a significant potential in bioenergy production either for their availability or for the biomass quality as fuel source (ash content, heating value and chemical composition) [2]. In Europe, more than 13 million tons (over dry basis) of pruning biomass are yearly available from permanent crops (olive grows, vineyard and orchard); most of them (about 80%) are located in the Mediterranean area, particularly in Italy and Spain [3].

In Italy, it is estimated an annual quantity of pruning biomass over 2.6 Mt (over dry basis) comes only from the olive groves [4]. In Apulia Region, where about 33% of the Italian olive groves are concentrated [5], according to [6], up to 7 Mg per hectare per year of green prunings are available for energy uses [6].

Although it is an abundant biomass resource, the exploitation of tree prunings for energy purposes is still limited, due mainly to logistics-related constraints [7]. These constraints are only partly related to the harvesting stage. In fact, several harvesting technologies are currently available on the market [8]. More notably, the transport of a low energy density biomass from small-sized and scattered tree plantations affects the overall economic sustainability of a pruning-to-energy value chain [9].

On the other hand, the location of bioenergy facilities is profitable in regions where olive groves and vineyards are concentrated, such as in the Mediterranean area [10]. In such conditions, in addition to economic profitability, local network based on agricultural residues could provide social and environmental benefits [11]. Nevertheless, pruning residues are not always considered a valuable resource, but are often a disposal problem [2]. In fact, prunings are usually disposed through open-air burning which releases a variety of pollutants and CO_2 emissions [12]. Alternatively, prunings are mulched, which is a costly labor intensive practice [13] and can consist a threat for transmitting soil disease [14].

To turn from an unsustainable practice such as open-air-pruning burning, plants that use tree crop pruning residue for energy purposes could be a solution with economic and environmental benefits.

In the literature, there are no studies assessing the economic and environmental sustainability of biomass power plants fueled with pruning residues based on real cases, while there are several studies that highlight the sustainability of pruning biomass for electricity production of hypothetical biomass plants [15]. Recently, in [16], the techno-economic and environmental viability of electricity generation using pruning biomass in nine different territories in Greece is investigated, highlighting a multiple potential benefit obtainable with new biomass plants by means of reducing fossil fuels use, providing new income opportunities and by achieving a low CO_2 power generation.

Similarly, other authors [15] evaluated if the use of residues from vineyards and olive groves may represent an economic opportunity for agricultural farms in 4 municipalities of Umbria region (central Italy) and if it contributes to reducing CO_2 emissions into the atmosphere. In particular, [15] showed that using pruning residues for power production in an area where plots are scattered and fragmented is not economically feasible, because of high supply costs, notably biomass transport and transfer costs. Nevertheless, [15] showed that the agro-energy chain proved to be sustainable from an environmental point of view for avoiding the emissions by pruning disposal.

In order to reduce the economic and environmental impacts related to logistics issues, some authors studied how to identify the optimal locations for prospective biomass power plants [17].

The optimal location of the power plant plays an important role in the supply chain in the bioenergy sector [18]; and, subsequently, in the economic and environmental sustainability of biomass to energy options [19]. A good planning strategy of the whole agro-energetic chain can minimize the overall costs and the environmental impacts [20].

In this framework, some authors focused their studies on the cost assessment of different step of the supply chain. The authors in [21] studied alternative techniques for mechanized recovery of olive tree pruning residues, emphasizing the profitability for energy use; the authors in [22] focused on the costs of olive tree pruning harvesting; while the authors in [23] calculated the costs of transporting biomass from field to plant.

Under an environmental point of view, some studies performed LCA analysis to evaluate the impact of bioenergy on a local scale and its potential to minimize greenhouse gas emissions [24] or to support public decision makers [25].

In the case analyzed in [26], the authors refer to the whole energy chain from vineyard pruning harvesting to the pilot plant for heating and cooling production for self-consumption in a winery. The authors estimated the return time of investment in no less than 8–9 years with no economic incentives and considered the production of electricity in a future perspective of recovering the exhaust fumes from the boiler in a thermoelectric module.

In Italy, there is only one power plant localized in the southern Italy (Apulia region) that uses exclusively olive pruning residues. This plant of 1 MWe is an interesting case study given its uniqueness at the European level [8,27]. In fact, this plant was chosen as case study in the framework of the AGROinLOG Project (Horizon 2020, Grant Agreement No 727961) aimed at demonstrating the technical, environmental and economic feasibility of new value chains based on agricultural waste and by-products. Moreover, this power plant was studied also in the uP-Running Project (Horizon

2020, Grant Agreement No 691748) aimed to unlock the European strong potential of woody biomass residues produced and to promote its use as energy feedstock.

In the literature, there are no studies assessing the economic and environmental sustainability of biomass power plants of 1 MWe fueled with pruning residues based on real cases or studies about its ecoefficiency ratio. To link the environmental impacts and economic assessment of a product or service, is possible to quantify the economic value of a product or service in relation to its environmental impacts. This approach is called the ecoefficiency ratio and it is a useful tool for the firm to achieve greater economic value with lower environmental impacts [28]. The ecoefficiency ratio is a performance indicator allowing the continuous improvement inside the firm and with respect to other firms [29] However, there are no articles in the literature about the ecoefficiency of pruning-based power plants or referred to fossil fuel-based power plants of small size [30].

Thus, the current study aims to fill this gap by analyzing on the one hand, the economic and environmental sustainability of a case study of power plant (1 MWe) that produces energy from olive pruning residues in southern Italy; on the other hand, its ecoefficiency ratio. In fact, to put together the environmental and economic assessment, the ecoefficiency ratio was used to measure the economic value (expressed in value added) per 1 Mg of greenhouse gases emitted into the atmosphere.

2. Materials and Methods

2.1. The Case Study

The study is focused on the agro-energetic supply chain composed by a small-scale power plant (1 MWe—with 16 workers) that produces electricity exclusively from olive tree prunings [31] and a harvest firm that supplies the prunings to the power station collecting them from local farmers. The plant is localized in Apulia region, South Italy, and works in a 10 km radius approximately 7000 hectares of olive groves (75% of the total utilized agricultural area) including nine Apulian municipalities. The total annual amount of prunings potentially is approximately of 25,000–26,000 Mg per year [31], compared to 8000 Mg of biomass annually supplied to the power plant.

According to the harvest firm's data, the pruning frequency is once every three years and pruning is usually done from January to June. Due to the long time between the two pruning stages, the biomass accumulation in the olive trees during pruning results high and the biomass productivity is in the order of 10 Mg_{fm} per hectare.

Moreover, the 1 MWe power plant has an annual operational capacity of 8000 h per year and it provides production of 8000 MWh annually [31].

In the agro-energetic chain studied are involved the local farmers (about 2400 farmers), who provide the olive prunings from their fields, and the power plant itself—through its subsidiary harvest firm—which organizes harvest and transport of olive prunings to the power plant. It is important to underline that on the one hand, farmers receive no payment for the pruning delivered to the power plant. In fact, the prunings are offered free of charge, because farmers no longer have to incur direct costs for disposing prunings from their fields (beside the raking phase for a field with less than 400 trees). On the other hand, a subsidized feed-in tariff of 0.28 €/kWh is secured to the power plant through a contract with the grid operator [31].

2.2. The Economic Parameters

To study the economic sustainability of the agro-energetic chain (the power plant and its subsidiary harvest firm), the profitability and efficiency ratios are calculated. In general, profitability ratios are indicators for the firm's overall efficiency, to measure its earning capacity [32]. Among profitability ratios, the return on owner's equity (ROE) ratio is one of the most used in economic analysis [32]. The ROE ratio measures the shareholders rate of return on firms' investment and it is calculated as net profit after tax divided by the total shareholders equity analysis [32]. Another important ratio is return on investment (ROI) that is usually used to measure the firm's ability to optimize the use of the available resources. This ratio measures the firm's efficiency in utilizing invested capital and is calculated as earnings before interest and tax (EBIT) divided by the capital employed.

All economic data (Tables 1 and 2) come from budgets (years 2016–2017) of both the power plant and the harvest firm.

Table 1. Economic data of the power plant: mean values (years 2016–2017).

The Power Plant	Euros
Balance sheet	
Net profit after tax	105,412
Equity	663,531
Total assets	6,571,704
Economic account	
Value of production	2,200,966
Costs of production	963,327
Gross value added	1,237,639
Earnings before interest and tax (EBIT)	285,001

Source: our elaboration on budget data of the power plant.

Table 2. Economic data of the harvest firm: mean values (years 2016–2017).

The Harvest Firm	Euros
Balance sheet	
Net profit after tax	6070
Equity	19,282
Total assets	408,297
Economic account	
Value of production	448,027
Costs of production	232,368
Gross value added	215,659
Earnings before interest and tax (EBIT)	25,085

Source: our elaboration on budget data of the harvest firm.

2.3. The Environmental Analysis

To study the environmental sustainability of the agro-energetic chain (the power plant and its subsidiary harvest firm), the GHG emissions are considered. The emissions into the atmosphere due to the pruning combustion for energy production come from internal data of the power plant, while the GHG emissions due to fuel consumption of the machine harvesters at firm level are estimated and come from the AGROinLOG project. In particular, considering an annual comminuted olive pruning biomass of 8000 Mg supplied to the power plant, the CO_2 emission of the pruning harvesting activities carried out by harvest firm (field stage) was determined considering a fuel consumption of the machine harvesters of 3.5 L per Mg of comminuted olive pruning (primary data) and an emission of 2.65 kg CO_2 per liter of diesel, according to [33] the following formula:

$$Fe = D*Ec*TP/1000 \tag{1}$$

where:

Fe = emission of CO_2 due to pruning harvesting and shredding—field stage (t CO_2/yield);
D = fuel consumed by the machines per Mg of olive pruning (L/Mg)
Ec = emission of CO_2 per liter of diesel (2.65 Kg CO_2/L).
TP = Total production of comminuted biomass from pruning (Mg/yield).

It is important to underline that the GHG emissions due to olive groves cultivation have not been considered in the study.

2.4. The Ecoefficiency Ratio of the Agro-Energetic Chain

To link the economic and environmental assessment of both the power plant and the harvest firm, the ecoefficiency method is applied [34,35] and it is expressed as the ratio between economic value and environmental impact of firms. In other words, the ecoefficiency ratio measures the value added of each firm per Mg of GHGs emitted into the atmosphere from both the power plant and harvest firm. The higher the ratio value, the higher the economic performance per unit of environmental impact. According to [36], the environmental and economic data should be come from the same data set. In fact, information based on the both annual budgets and internal data of the two firms have been collected. The economic aspect is expressed as the gross value added (GVA) that is the difference between total revenues and costs (including raw materials, services, other operating expenses and other than fixed assets) [34].

3. Results and Discussions

3.1. The Economic Aspects

To assess the economic sustainability of an agro-energetic chain, the ROE and ROI ratios are calculated for the power plant and harvest firm (Tables 3 and 4). According to some authors [37], financial stability is one of the main concerns of firm management, and thus, ROE is an important ratio to consider in the analysis. The findings showed both firms have a good ROE ratio, which is a measure of a firms' success in generating profit for shareholders. In fact, according to [38], a good rate return of ROE is obtained if ROE is > of 12%. In our case, the whole agro-energetic chain (the power plant and harvest firm) show a ROE ratio of 15.89% and of 31.48%, respectively. Moreover, the ROE ratio of the harvest firm (31.48%) is higher than the power plant one (15.89%).

Table 3. Economic results of the power plant.

The Power Plant	Euros
Net profit after tax	105,412
Equity	663,531
ROE ratio	**15.89%**
Earnings before interest and tax (EBIT)	285,001
Total assets	6,571,704
ROI ratio	**4.34%**
Value of production	2,200,966
Costs of production	963,327
Gross value added	**1,237,639**

Source: our elaboration on budget data of the power plant.

The ROI ratio, instead, indicates how much the profit gained by using the entire assets owned by the firm and to have a good ROI ratio, it should be > of 2% [38]. In our case, both firms showed good rates return, that are 4.34% and 6.14% respectively.

It is important to underline that even if the power plant's ratios (i.e., ROE, ROI) are lower than the harvest firm ones, these findings are very interesting if you think that it is a power plant and the harvest firm dealing only with the olive pruning harvesting activities on the field.

Unfortunately, there are not many studies evaluating the economic aspects of a real power plant with similar technical characteristics to our case study (feedstock, process and size) which could help us to evaluate the findings. However, some authors [26] studied the economic convenience of a pilot plant for bioenergy and showed a return times of no less than 8–9 years. In our case, the power plant started in 2010 and the return times were of no less than 6–7 years; in fact, the power plant showed good rates of return (ROI) of 4.34% (based on mean values) during years 2016–2017.

Table 4. Economic results of the harvest firm.

The Harvest Firm	Euros
Net profit after tax	6070
Equity	19,282
ROE ratio	**31.48%**
Earnings before interest and tax (EBIT)	25,085
Total assets	408,297
ROI ratio	**6.14%**
Value of production	448,027
Costs of production	232,368
Gross value added	**215,659**

* Source: our elaboration on budget data of the harvest firm.

Moreover, as mentioned above, the power plant provides production of 8000 MWh annually [31], keeping up a cost of production of 120 €/ MWh. Our findings are similar to [39], a study where it has been shown that there is a cost of production of 130 €/ MWh for a biomass power plant; 64 €/ MWh for a coal fired power plant and a cost of production of about 73 €/ MWh for a coal and biomass-fired power plants in the UK. However, it is important to underline that the technology, the feedstock and the size of the power plants studied in [39] were different with respect to our case study. In particular, they are large sized pulverized fuel combustion power plants of 650 MW (versus our plant that was of 1MWe) and the biomass used is wood pellet imported (alone or in co-firing). On the contrary, in our case, local olive tree prunings were used. The latter is an important aspect under the economic and environmental perspective, since our power plant uses exclusively agricultural residues supplied from a ten kilometers radius basin that otherwise would be disposed by farmers with open-air burning causing high economic and environmental impacts.

At farm level, instead, some authors [15] evaluated if the use of agricultural residues may be an economic opportunity for farms and showed that using pruning residues for power production in an area where plots are scattered is not economically feasible. The scatter spatial distribution of agricultural residues plays an important role in the costs determination. In fact, a good planning strategy of the whole agro-energetic chain can minimize the overall costs [20]. Moreover, the location of bioenergy facilities is profitable in regions where olive groves and vineyards are concentrated such as in the Apulian region [10]. In our case, the organizational model (the power plant and harvest firm, where the harvest firm works in a 10 km radius around the power plant) allows a complete control over all the production steps and the harvest firm, taking over the logistics operations, has allowed to save significant costs as compared to the use of independent contractors outside the power plant [31]. Moreover, according to [15], costs for ash disposal amount to 3% of the total biomass used, with a withdrawing cost of 4 € per Mg. In our case, according to Italian Ministry of Environment, Land and Sea Protection (protocol number 0003987.15.03.2018), the power plant has been officially authorized to use the biomass ash as a fertilizer, saving costs due to ashes disposal.

3.2. The Environmental Aspects

To assess the environmental aspect of an agro-energetic chain, the GHG emissions are calculated for the power plant and harvest firm.

The total environmental impacts of agro-energetic chain expressed in GHG emissions can be summarized in Table 5.

Some authors [15] showed that the agro-energetic chain proved to be sustainable from an environmental point of view (about 137 Mg of CO_2 emitted per 1 Mg of biomass). In our case, considering an annual comminuted olive pruning biomass of 8000 Mg supplied to the power plant, the CO_2 emitted into the atmosphere is 68 Mg of CO_2 emitted per 1 Mg of biomass.

Table 5. GHG emissions of the pruning agro-energetic chain in Calimera (LE, Italy).

Agro-Energetic Chain	kg CO_2 eq per year
The power plant	
GHG emission	469,000
The harvest firm	
GHG emission	74,000
Total	**543,000**

Source: our elaboration on the firm's data.

In addition, as mentioned above, the power plant provides a production of 8000 MWh annually [31], emitting about 68 kg of CO_2 into atmosphere per 1 MWh. Our findings are better than the ones in reference [39]. In fact, according to [39]'s study in the UK, a biomass power plant emits 898.85 kg of CO_2 into atmosphere per 1 MWh; while a coal fired power plant emits 834.7 kg of CO_2 per MWh and a coal and biomass-fired power plant emits about 829.8 kg of CO_2 per MWh. These high differences in the results depend on both different technical characteristics of plants and by different wood management. In fact, in our case the plant use agricultural residues comes from within a 10 km radius from the plant, while in the [39] study generic wood pellets imported from America are used.

Moreover, according to [31], on the one hand, producing 8000 MWh of electricity, the power plant allows to avoid the emission into the atmosphere of 5359 Mg CO_2eq per year compared to electricity production from fossil sources. On the other hand, thanks to the existence of the agro-energetic chain (the power plant and its subsidiary harvest firm), the farmers have their fields cleaned and no longer need to resort to field burning, which is harmful for the environment and costly also [31].

Finally, the findings showed that the combustion of pruning residues for electricity generation is very beneficial not only by reducing fossil fuels use but also by leading to a low CO_2 emissions into the atmosphere [16].

3.3. The Ecoefficiency Ratio

In Table 6, emissions in the atmosphere per gross value added (€) produced by the pruning for energy supply chain were analyzed. The higher the ratio value of firm, the higher its economic value per unit of environmental impact. The ecoefficiency of each firm making up the energy supply chain analyzed showed that the harvest firm had a better ecoefficiency ratio per unit of GHG emitted into the atmosphere compared to the power plant. In fact, the harvest firm shows a value added of 2.91€ per Mg of greenhouse gases emitted into the atmosphere.

Table 6. Ecoefficiency ratio of the pruning agro-energetic chain in Calimera (LE, Italy).

Ecoefficiency Index	Unit	Value
The power plant		
GVA	€/y	1,237,639
GHG emission	Mg CO_2 eq/y	469,000
Ecoefficiency ratio	€/Mg CO_2 eq	**2.64**
The harvest firm		
GVA	€/y	215,659
GHG emission	Mg CO_2 eq/y	74,000
Ecoefficiency ratio	€/Mg CO_2 eq	**2.91**

Source: Our elaboration on the firm's data.

Moreover, the power plant's ecoefficiency ratio is slightly lower than harvest firm one (−9%); in fact, the power plant shows a value added of 2.64 € per Mg of greenhouse gases emitted into the atmosphere. This finding appears to be even more interesting due to the different sectors (industrial and agricultural) that the two firms belong. In fact, contrary to what was expected, the two firms, constituting the energy chain based on olive tree pruning, have shown similar ecoefficiencies.

The findings represent a novelty due to the characteristic of the supply chain, quality of the primary data used, and ecoefficiency evaluation method used. This is due to the novelty of this research that is a combination of economic and environmental aspects never performed before on a real case of a pruning-based biomass power plant. As mentioned above, the biomass plant analyzed is unique in Europe of its kind (in technical terms and for residues used). Moreover, there is a lack of studies that analyze the ecoefficiency of energy supply chains in the literature. In addition, the economic and environmental parameters used for the ecoefficiency calculation can vary from one study to another [35]. In fact, as mentioned above, the ecoefficiency is a ratio between product or service value and its environmental impact, however, there are numerous ways in which ecoefficiency can be calculated. The authors in [35] provided a set of indicators that cover the broad spectrum of use of products and services, and environmental impacts The selection of value indicators depends upon the ways in which the ecoefficiency indicators will be used for decision making in firms. For example, firms may want to analyze the ecoefficiency ratio using indicator as profit (or gross value added, etc.) on GHG emissions (or ozone depleting emissions, water consumptions etc.). Firms choose indicators that best serve their decision making [35]. Moreover, using an economic indicator divided by the environmental impact provides a useful index to compare within the company throughout time [29]. In our case, following [34]'s study, the gross value added (GVA) (that is the difference between total revenues and costs) and GHG emissions have been chosen to calculate the ecoefficiency ratio. The GVA has been chosen because it is an economic measure of firms and represents the value sufficient to remunerate labor, capital and land in adequate way [40]. In the literature, no studies evaluating the ecoefficiency a power plant of 1 MWe (biomass or fossil fuel basis), using GVA method, are available and for this reason, the authors believe that this study could fill a knowledge gap in the current literature.

4. Conclusions

This research aims to analyze the economic and environmental sustainability of a 1 MWe power plant that produce electricity exclusively from olive pruning in Southern Italy, that represent a unique case-study in Europe. The GVA and GHG emissions combined for the ecoefficiency assessment of the energy supply chain studied represent a novelty in literature.

The findings showed the environmental and economic feasibility of a circular economy model turning agricultural waste into energy. Furthermore, the results showed a similar ecoefficiency ratio of both the harvest firm and the power plant which provide the solid biofuel and the energy, respectively. These results highlighted a good balance in the ecoefficiency ratio of the two elements making the energy supply chain, and the evaluation of ecoefficiency through the GVA method could be a valid tool for the two firms to assess their ecoefficiency over time.

CO_2 emissions generated by the studied energy chain, per MWh of energy produced, were lower than those generated by large biomass or coal-fired power plants (>500 MW).

This result is certainly conditioned by the fact that the short energy supply chain based on olive tree pruning requires far fewer steps than the supply chains of large power plants that need much larger biomass supply basins and intermediate steps, or long distances to transport the fuel from the extraction site to the processing plant.

From an economic point of view, both the firms studied have positive ROI, ROE and GVA values. In particular, GVA of the energy power plant derives from the subsidies of 0.28 €/kWh provided by the grid operator. Future studies could be focused on the minimum price on which the power plant can receive to remain on the market. Moreover, the results could be useful insights to push new entrepreneurs towards new business models based on the circular economy concept. In particular, on the one hand, a business model like that showed could allow entrepreneurs to reach good profits, helping local farms to avoid pruning disposal costs. On the other hand, this business model could provide huge environmental benefits either by avoiding open-air burning of prunings and contributing to the replacement of fossil sources with renewable sources for electricity production.

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Conflicts of Interest: The authors declare no conflict of interest.

Endnotes:

Nomenclature

kWh	kilowatt-hours
MWh	Megawatt-hours
MWe	Megawatt electrical
Mg	Megagram
Fe	emission of CO_2 due to pruning harvesting
D	fuel consumed by the machines per Mg of olive pruning
Ec	emission of CO_2 per liter of diesel
TP	total production of comminuted biomass from pruning
CO_2 emissions	carbon dioxide emissions
EBIT	earnings before interest and tax
ROE	the return on owner's equity
ROI	the return on investment
GVA	the gross value added
Ecoefficiency ratio	ratio between economic value and environmental impact of firms
CBA	cost-benefit analysis

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