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Gasification of agricultural residues to support the decarbonization of the transport sector via electricity generation: a case study

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Abstract. The gradual electrification of transport, particularly private cars, requires widespread electricity availability and potential peak demand in rural or underdeveloped regions could strain the existing electricity network. Therefore, exploring distributed electricity generation is crucial to reduce grid demand and can be an opportunity to promote low-carbon technologies. In this research work we analyze the potential contribution of a biomass gasifier, fueled by vine prunings, in supplying electricity to a local site for electric vehicles charging. The performance of the system is assessed from a technical, economic and environmental point of view. In particular, the specific equivalent CO_2 emissions of the system are compared to the alternative emissions of the national power grid, considering the estimated charging profiles based on available patterns from real case studies that incorporate different users' behaviours and preferences. The electricity produced by the gasifier has a calculated supply chain carbon intensity of 134 $gCO_{2e} \cdot kWh^{-1}$, which can be sharply reduced to -34 $gCO_{2e} \cdot kWh^{-1}$, indicating a carbon-negative process, when the carbon sequestration of the co-produced biochar is considered. These figures should be evaluated against a weighted average carbon intensity of the national electricity mix equal to 384 $gCO_{2e} \cdot kWh^{-1}$ in 2018, while the same figure for 2030 ranges from 141 $gCO_{2e} \cdot kWh^{-1}$ to 226 $gCO_{2e} \cdot kWh^{-1}$ depending on the future scenario that is considered. The economic assessment estimates payback times between 6 and 8 years with an average utilization factor of the charging station equal to 14% and a charging price equal to 0.62 €/kWh. In addition to the emission savings that are obtained, this approach could generate further positive effects on the territory: a) the production of electricity allows rural areas to establish their sustainable electric transportation network, reducing their marginalization; b) the production portfolio of farms or agricultural consortia is diversified; c) create a carbon-negative recovery chain for lignocellulosic waste and offers a sustainable solution for their disposal. The results of this analysis can be of use for other researchers dealing with similar topics, and for policymakers that aim to compare available solutions for the decarbonization of the transport sector.

1 Introduction

The progressive electrification of road transport is the cornerstone of the European Commission's *A clean planet for all* strategy [1] which lays the foundations for reducing the use of fossil fuels by encouraging the use of an energy mix with a lower environmental impact. The transport sector is among the largest contributors to EU greenhouse gas emissions [2] and, in this context, electric mobility based on full electric (mostly battery electric vehicles - BEV) and plug-in hybrids (PHEV) seem to offer a possibility for the decarbonisation of the sector. The European vehicle market is constantly growing and counted almost 2 million EVs in 2022 with a 21.6% share of new registrations [2], however, high purchase costs and limited driving range of BEV still remain important considerations for consumers and prevent their spread. Although the driving range has more than tripled in the last 10 years, settling at an average value of 393 km (measured at type-approval) [2], the recharging infrastructure is still immature and must develop in a capillary way offering both adequate recharging power and competitive charging costs compared to the fossil alternative. In the Italian scenario these problems must be solved by dealing with a highly uneven territory, with recharging stations concentrated mostly in urban centers, where the electricity network is more structured [3]. In addition to this, the cost of energy at the recharging station has prices even double compared to home charging and according to the report of the European Alternative Fuels Observatory, the Italian market sees average prices for home charging of around 0.31 €/kWh, while for public AC and DC charging respectively 0.55 €kWh^{-1} and 0.68 €kWh^{-1} [4]. It is therefore necessary to find strategies for the diffusion of charging points outside the urban centers, involving the so-called marginal areas in the electrification process. These regions are typically agricultural and generate significant amounts of organic waste annually, much of which often remains unutilized. This is the case of the wine production chain: to guarantee production and quality, the vine must be pruned annually and this process produces large quantities of wood waste (from 1 to 5 tons/ha per year) [5], which to date have never found a reliable disposal chain. The solution nowadays mainly adopted is to shred and bury them in the field but this current practice can lead to the spread of pathogens that overwinter in the shoots of the plant [6]. To limit this risk, the practice of in-situ burning is still permitted with the consequent inefficient use of the residual biomass and the production of harmful and greenhouse gas emissions.

Alternatives for the recovery of prunings include their use as a source for fuels and secondary raw materials [7], their conversion into biochar through pyrolysis [8] or thermal/electrical energy through different processes. These practices enhance industrial profitability and promote sustainability. Regarding the direct energy conversion, several studies focus on the combustion of vine shoots for heat generation both with domestic [9] and industrial boilers [10] with good results only for the latter. Direct electricity production is still a little investigated topic, with studies often referring to lab-scale apparatus such as the organic Rankine cycle reported by Villarino et al. [11] or through studies such as those from Biagini et al. [12] and Brito et al. [13] that employ the thermochemical gasification process but without inserting it in a circular economy context. This aspect has already been investigated by the authors through the modeling of Combined Heat and Power (CHP) application for a winery, showing how the use of vine prunings is advantageous only for high electricity and thermal energy prices [14].

The aim of this work is to bring the production of electricity from vine pruning towards more profitable services such as charging EVs in non-urban areas, using the winery as a hub for the collection of prunings, their energy conversion, and the sale of energy to private transport. Wineries are often located at the meeting point between urban and agricultural areas and are well connected to roads with high vehicular traffic. Furthermore, wineries have large outdoor spaces that are often unused from winter to summer, which could serve as storage for the collected biomass to be dried. Part of the space can instead be used to install a charging station that can serve several EVs at the same time. At the same time, local energy generation aligns with the need for potential peak power reduction in rural or underdeveloped areas with limited infrastructure. Therefore, it is crucial to explore alternatives for distributed electricity generation that can serve as low-carbon solutions, reducing reliance on the national grid.

This study examines the potential of a biomass gasification system to convert vine pruning pellets into electricity for charging EVs at a local site. The gasification unit, specifically the Power Pallet 30 by All Power Labs [15], is a micro-scale power generation system designed to convert solid woody biomass into syngas, with biochar as a byproduct. The syngas fuels an internal combustion engine, generating 20 kW of electrical power. Biochar contributes to making gasification a promising carbon-negative technology. Multiple generators operating in parallel power a battery energy storage system (BESS) that provides electrical energy to two 150 kW high power (or ultra-fast) EV charging columns (HPCs).

The performance of the system is assessed from a technical, economic and environmental point of view. In particular, the specific equivalent CO_2 emissions of the system are compared to the alternative emissions of the national and local power grids, considering different charging profiles based on available patterns from real case studies that incorporate different users' behaviours and preferences.

2 Materials and methods

The case study under investigation considers the creation of a recharging station located in a winery, involving the installation of a series of biomass power production units, a battery energy storage system, and two HPCs each capable of delivering a peak power of 150 kW. The following paragraphs describe the energy production/distribution subsystems, the model used to simulate vehicular traffic in the proximity of the charging station as well as the economic and environmental assessments.

2.1 Energy production and distribution systems

The production of electrical energy from vine prunings was considered to be achieved by means of the thermochemical conversion process of gasification. During the gasification process, the biomass is fed into a gasifier (or gasification reactor) where air, oxygen, or other gasification agents react with the feed material [16]. The result is the thermochemical degradation of the solid wood into fuel gas (syngas). When air is used, the syngas composition consists of combustible compounds: H_2, CH_4, and CO, and non-combustible compounds: CO_2, H_2O, and N_2. In this case, the lower heating value (LHV) of syngas ranges between 4-7 MJ/Nm^3 [17].

The syngas undergoes a cooling and filtration stage to reduce tars (mainly hydrocarbons) and particulate matter to below the limit of respectively 30 and 100 mg/Nm^3 [18]. It is then utilized to power an internal combustion engine, which generates electrical power through a generator.

This study examines the installation of three APL PP30 generators, which had previously yielded positive results when operated with pellets made from vine prunings, as reported by the authors [19]. The scenario considers the installation of three PP30 gasifiers, operating in parallel, for a total installed electrical power of 60 kW, while the biomass specific consumption at nominal power was measured (in previous experimental campaigns) at 1.15 kg kWh^{-1} of dry biomass.

The charging station is considered to be open 24h, five days a week for 52 weeks, for an annual total of 6240 hours. Discontinuous operation has been considered to allow for necessary maintenance tasks such as filter replacements, engine cleaning, and char vessel emptying.

In order to decouple the power generated by the gasifiers from the actual power available for charging vehicles (peak shaving), the installation of a BESS is necessary. The installed BESS is considered to have a capacity of 300 kWh and a round-trip efficiency of 96%. The storage system is hypothesised capable of delivering enough current to power both charging columns at full load in the case of parallel charging of two vehicles. In this analysis, no distinctions in efficiency were made between vehicles charging in AC and those charging in DC.

To simulate a more realistic scenario, it has been hypothesized that the power generated by the gasifiers varies incrementally, based on the State of Charge (SoC) of the BESS, rather than operating in a simple on-off mode:

- SoC = 100%: PP30 at idle, no power is generated;
- SoC $\geq$ 90%: the power supplied by the PP30 is reduced to 75%;
- SoC $\geq$ 85%: the power supplied by the PP30 is reduced to 60%.

This approach is considered to reduce the total power generated by the PP30s running in parallel and, in this preliminary analysis, the biomass generator efficiency is considered to be constant over the entire turn-down ratio. The next section describes the model that leads to the definition of electrical loads resulting from vehicle charging.

2.2 Vehicle flow characteristics

The simulation of the vehicular traffic on the road, where the HPCs are installed, is carried out through the Monte Carlo method [20]. In this regard, the following variables were evaluated:

- **Vehicular flow intensity:** the data collected by ARERA [3] for the Italian scenario shows that, on average, HPCs are used for 10-12% from 00:00 AM to 08:00 AM, 53-55% from 08:00 AM to 4:00 PM, 33-36% from 4:00 PM to 00:00 AM. However, this data is highly variable, and to obtain a more accurate picture, we used data from a major artery (SP468) in the city of Carpi that leads out of the city, passing near one the Riunite&CIV winery [21]. Based on this, the probability of passing vehicles is modeled using a normal distribution, divided into three daily time ranges with the following characteristics:
  - Range 1: average at 08:00 AM with a standard deviation of 40 minutes;

– Range 2: average centered at 1:00 PM with a standard deviation of 2 hours;
– Range 3: average centered at 6:00 PM with a standard deviation of 40 minutes.

In the three ranges, the total passage of 100, 50, and 100 vehicles was considered respectively. In this preliminary calculation, it was decided to ignore the contribution from vehicle traffic during the night due to the lack of available data. Figure 1 shows one of the possible daily trends generated in the model.

- **Vehicle type:** to increase the detail of the simulation, four different types of vehicles are considered, the occurrence of which was calculated randomly and whose data are shown in Table 1.
- **Vehicle state of charge (SoC):** for each passing vehicle, a different SoC between 20% and 80% was considered. The SoC leaving the charging station is considered as a random variable between 60% and 80%. A minimum recharging time of 5 minutes has been chosen, if the vehicle requires less than 5 minutes, it does not stop to recharge. The recharge power is determined by the lesser of the vehicle's maximum recharge capacity or the station's maximum power output.

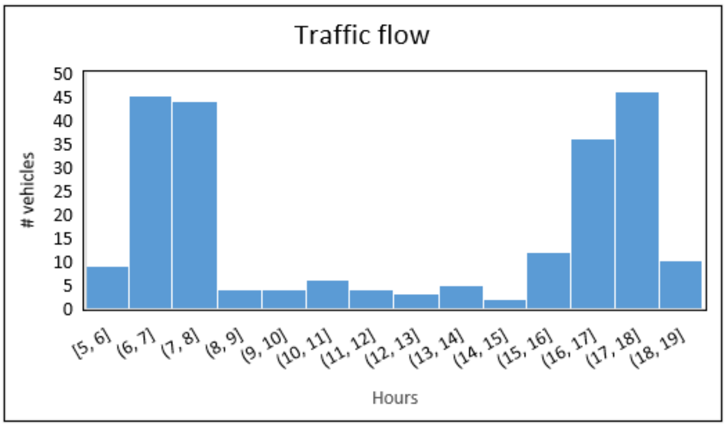

Figure 1: Daily trend of the traffic flow generated by the model.

Table 1: Characteristics of the battery electric vehicle considered in this work.

Car model	Consumption WLTP [km/kWh]	Range [km]	Charging power [kW]	Battery capacity [kWh]
1	7.1	533	250	75
2	6.4	362	100	50
3	4.9	270	50	40
4	7.2	227	35	27

Using this scheme, the daily load was calculated and the biomass consumption was estimated, reporting the data on an annual basis. This allows a preliminary economic analysis as described in the following section.

2.3 Economic assessment

Annual data were used to calculate earnings and costs. Earnings were derived from the sale of energy for recharging vehicles, with a specific price set at 0.62 €kWh^{-1}, based on the average values indicated by [3] for the Italian market of ultra-fast charging stations (>150 kW). Variable costs, attributable to the operation and maintenance of gasifiers, were considered to be 0.08 €kWh^{-1} based on the energy generated from the PP30s. Maintenance or replacement costs for the BESS and HPCs were not taken into account in this preliminary work due to the absence of a chosen specific commercial solution. For the PP30 a specific cost of 3250 €kW^{-1} was considered (as per manufacturer quotation), generating a total cost of 195'000 €, for the BESS a cost of 450 €kWh^{-1} was considered [22] with a total cost of 135'000 € while for the charging columns infrastructure the specific cost is 340 €kW^{-1} [3] for a total cost of 102'000€. The cost of biomass was assumed to be 178 €ton^{-1} as a precautionary value from Toscano et al. [5]. This price take into account the harvesting and the conversion of the biomass into pellets. The calculation of the NPV was carried out considering a discount rate that varies between 5% and 10%, taking into account that for investments in the biomass sector, a typical discount rate is set to 6% [23]. A net present value (NPV) assessment was then carried out, factoring in expenses and revenues generated by utilizing the gasifier as an energy source. The analysis is mainly described by Equation 1:

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \tag{1}$$

Where:
NPV = represents the current value of future cash flows (€).
I_0 = Initial investment, the cost at time zero (€).
CF_t = Cash flow at time t, which can be positive (inflows) or negative (outflows) (€).
r = Discount rate, reflecting the rate of return or cost of capital (%).
n = Number of years, indicating the time span over which cash flows occur and are discounted.

The discounted payback time (PB) (i.e. the period during which the cumulative NPV of the project reaches zero) was calculated using two different discount rates: 5% and 10%.

2.4 Life cycle assessment of electricity produced from vineyard prunings

The environmental impact of the electricity delivered by the charging station was estimated considering the counterfactual scenario in which the electricity is sourced from the grid. The estimation was based on a Life Cycle Assessment (LCA) comparison of the emission factors of grid and biomass-derived electricity. In order to properly account for the specificities of the case under study, a dedicated LCA study was designed for the electricity produced from the gasification of vineyard prunings. The LCA was conducted following the methodological framework of the ISO 14044 standard [24] and the guidelines set out in Annex VI of EU Directive 2018/2001 (REDII) [25], dealing with emissions accounting of electricity produced from biomass feedstocks. The remaining of the section describes the value chain under study and the main assumptions and data sources used in the analysis.

2.4.1 Goal and scope The goal of the LCA study was to estimate the carbon intensity of electricity produced from the gasification of pellettised vineyard prunings. The functional unit used throughout the analysis was the kWh of electricity delivered to an electric vehicle, and its carbon intensity was compared to the alternative scenario in which that kWh is sourced from the utility grid.

In agreement with REDII methodology, the LCA analysis considered all the emissions arising from the energy and material flows in the processing, transport, distribution and end-use phases of the value chain. Still following REDII methodological principles, embodied emissions related to the manufacturing of the various components of the system (pelletting machine, gasifier, charging station, battery, etc.) were excluded from the analysis, as they usually constitute a modest part of the total emissions. Future studies will focus on the integration of construction emissions into the LCA analysis, to enable a more fair comparison with the carbon intensity of grid electricity. As concerns emissions from vineyards cultivation, current agricultural practices regard vineyard prunings as an agricultural waste to be disposed of or as a low-value product used for cogeneration [14]. For this reason, these were excluded from the analysis.

The charging station was located in Carpi, in the province of Modena, while prunings were assumed to be collected from the nearby vineyard district. A conservative assessment of yearly biomass availability [26] showed that considering a collection basin with a diameter of 15 km would cover the full operation of the gasifier, based on the simulation described in section 2.1. Therefore, all the stages described in the following were assumed to take place within this basin.

The boundaries and main stages of the value chain are reported in Figure 2. The analysis begins with the collection of agricultural residues from the vineyard and terminates with the production of electricity from prunings pellets, also featuring the generation of biochar as a by-product of gasification. The

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modelling of the value chain from pruning harvesting up to the pelletting stage was largely based on the paper by Ilari et al. [27]. Plants are pruned manually, with prunings being laid down at the centre of the vineyard rows. Then, prunings are collected and turned into chips by a loader-shredder machine [28]. Next, chipped prunings are loaded on an agricultural trailer and transported to an on-field, open-air storage, where they are covered with waterproof sheets and left to dry from one to eight months.

At the end of the drying period, chipped prunings have a moisture content around 18% [27], compatible with the pelletting process. Pelletisation is carried out on-field, by transporting a mobile pelletting machine [5] to the storage site by means of a tractor with trailer. The main components of the machine are the grinding mill and pelletting system, both fed by a 35-kW electric motor. Prunings pellets are then transported by tractor and trailer to the charging station, where they are fed to a 20-kW gasifier to produce electricity. Non-CO_2 greenhouse gas emissions from the gasifier (CH_4 and N_2O) were neglected, as the gasification process through the PP30 was found to emit less CH_4 and N_2O with respect to the counterfactual scenarios in which the biomass is burnt on-field or left to decompose [29].

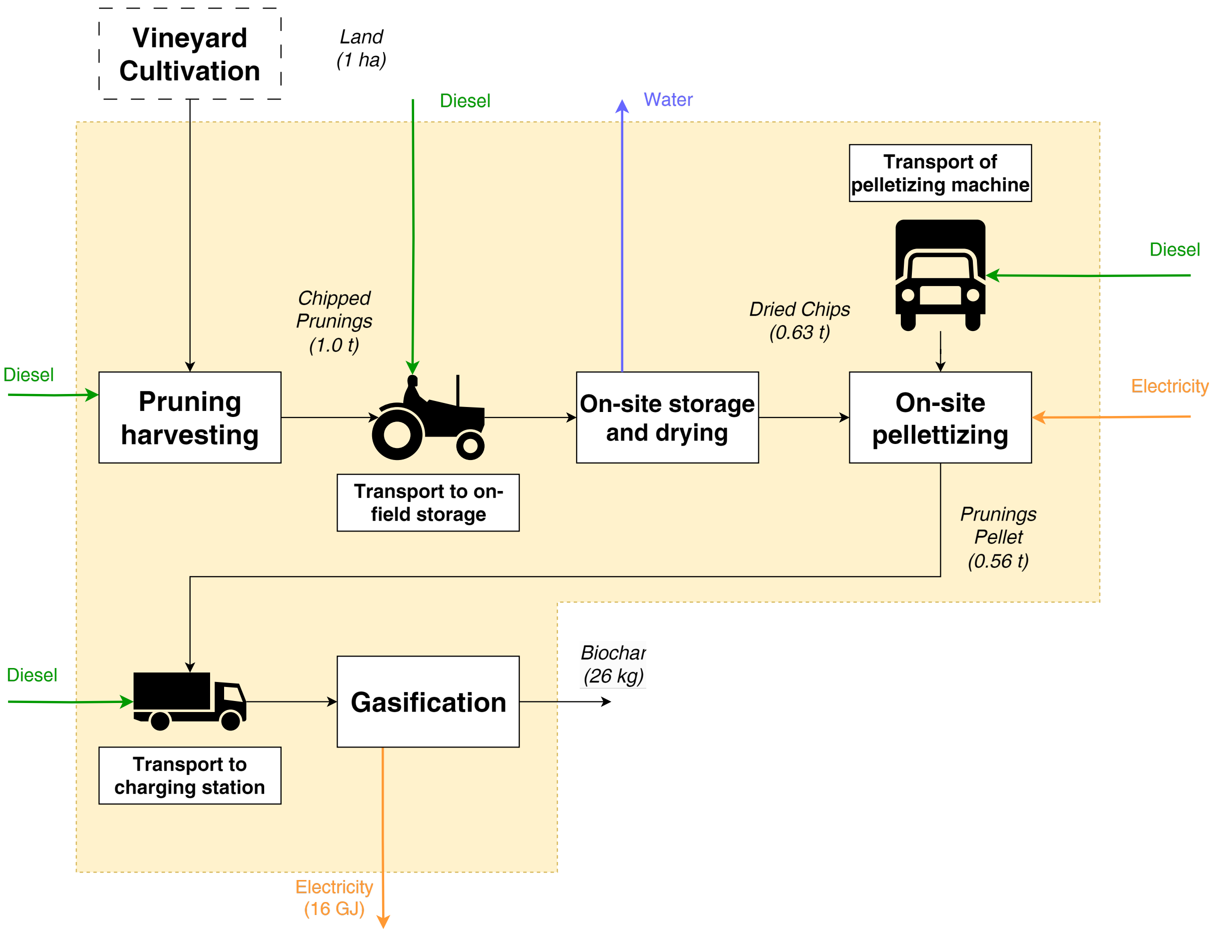

Figure 2: Stages of the value chain for the production of electricity from the gasification of vineyard prunings pellets. Main mass and energy flows are reported in brackets (figures refer to unit hectare and year). Mass flows are on wet basis.

Biochar is also produced as by-product of the gasification process. No upstream emissions were allocated to the char. At the output of the gasifier, the biochar has a high ash content and is particularly rich in copper (Cu), due to the intensive treatment of vineyards with Cu-based fungicides. Nevertheless, a recent study conducted by Santunione et al. [30] showed that the Cu-content of biochar produced from vineyard prunings is still below the limits set by Italian Decree n. 75/2010 regarding soil amendments, as well as below the threshold set by the European Biochar Certificate (EBC) guidelines [31]. The biochar is therefore eligible for use as soil amendment in organic carbon restoration projects, and could consequently generate carbon credits under carbon offsetting mechanisms, by virtue of its long residence time in soil [32]. In this work, it was assumed that the generated carbon credit can be discounted from the carbon intensity of the electricity produced. While methodologies are in place for the calculation of biochar carbon credits – e.g., that developed by Verra [33] – this preliminary analysis used a simplified approach to calculate it, solely based on the stoichiometric conversion of biochar fixed carbon content into carbon dioxide equivalent.

2.4.2 Life cycle inventory The Life Cycle Inventory (LCI) dataset for this study was constructed from various literature sources. Properties of prunings chips and pellet (such as moisture content, calorific value and bulk density) were sourced from Toscano et al. [5] and Zanetti et al. [9]. An average prunings yield of 1.0 $t\ wet\ matter \cdot ha^{-1}$ was assumed in the baseline scenario, taking the low-end of the range reported in literature [34].

Data on energy consumption of the harvesting machine and the pelletting system were sourced from Toscano et al. [5]. The diesel consumption of the harvesting machine was estimated around 4.2 $litres \cdot ha^{-1}$, whereas the pelletting system absorbs 0.17 $kWh \cdot (kg\ \ wet\ matter\ pellet)^{-1}$. The gasifier was modelled on the PP30 machine described in Morselli et al. [14]. The gasifier produces 0.87 kWh (16.2% energy efficiency) and 50 g of biochar for each $kg\ dry\ matter$ of pellet.

Concerning transport activities, representative vehicles were selected and conservative transport distances were assumed. Prunings chips are loaded on an 8 m^3 trailer pulled by tractor an moved for a maximum of 2.5 km to the storage site. Prunings pellet are moved from the storage site to the charging station by mean of a $40{-}m^3$ trailer pulled by a $100{-}kW$ tractor [5]. The transport distance between the storage site and the charging station was conservatively set to 15 km. The pelletting machine is carried to the storage site from a 15 km distant deposit by a 12-t truck.

Emission factors for electricity (low voltage) and diesel were sourced from Annex IX of REDII Implementing Regulation [35]. As concerns the calculation of biochar carbon credit, a fixed carbon content of 80% was assumed [36], and a stoichiometric conversion coefficient of 3.664 $gCO_{2e} \cdot gC^{-1}$ was used.

2.4.3 Impact assessment Only the Climate Change impact category was considered in the analysis. Future studies might focus on other impact categories, in order to compare the effect of different management practices of vineyard pruning. Climate-altering emissions considered were carbon dioxide, methane and nitrous oxide, which were converted to carbon-dioxide equivalent CO_{2e} using Global Warming Potential (GWP) values from the most recent IPCC AR6 report [37]. The carbon intensity of produced electricity was expressed in $gCO_{2e} \cdot kWh^{-1}$and emission savings were calculated as percent reduction from the carbon intensity of grid electricity.

2.4.4 Uncertainty evaluation In order to assess the impact of key uncertainties in the input dataset, a sensitivity analysis was conducted. In detail, two uncertainty elements were considered: the yield of prunings per hectare and the transport distance of pellets from the storage site to the charging station. These constitutes major uncertainty elements: the first because, as observed above, the prunings yield is reported to vary significantly by previous studies. The second because transport distance will strongly depend on the availability of local biomass. A yield lower than expected, as well as the lack of participation of local farms, could push towards the procurement of biomass from further vineyards.

Prunings yield, set to 1.0 $t\ wet\ matter \cdot ha^{-1}$ in the baseline scenario, were varied from 0.30 to 5.0 $t\ wet\ matter \cdot ha^{-1}$, based on literature ranges [34] and authors' previous experience in this vineyard district. Pellet transport distance, set to 15 km in the baseline scenario, was varied in the range 7.5 - 22.5 km (±50%), to account for the sourcing of biomass from further vineyards.

3 Results and discussion

3.1 Results from the operational analysis of the power system

The generation of vehicular traffic according to what is reported in Section 2.2 has led to different turnout profiles at the columns from day to day and an example is shown in Figure 3. The graph shows that

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the BESS reaches the maximum capacity value only before the first discharge, following the loading that took place during the night in which no vehicle recharges were assumed. During the day, the discharge profile of the BESS is driven by the intensity of the vehicular traffic. The gasifiers operate at maximum capacity for most of the time and their power output is reduced during the early morning and midday hours only, when the demand for vehicle recharging is assumed to be minimal. Figure 4 instead shows the annual trend of the energy drawn from each charging station. The model always prioritizes filling the first charging station before the second, resulting in a consistent asymmetry in the discharged energy.

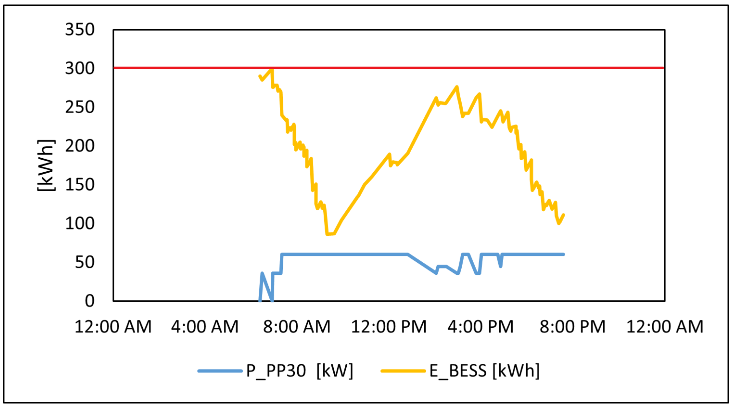

Figure 3: State of charge of the battery energy storage system and actual power of the gasifiers.

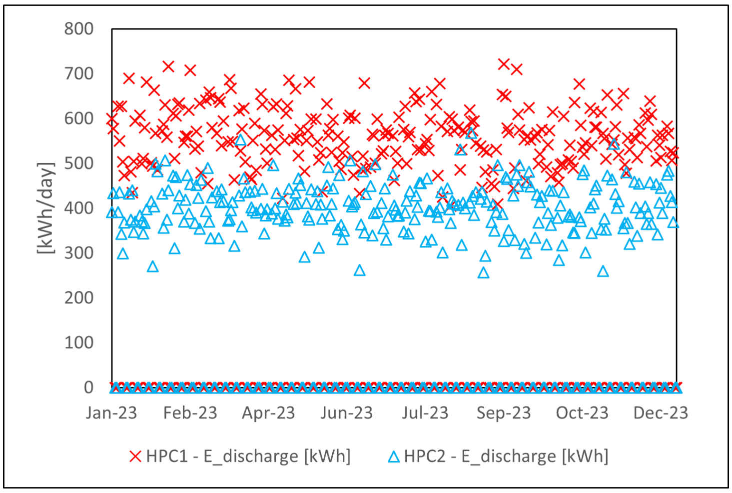

Figure 4: Energy drawn from each of the two charging stations during the year.

In the annual simulation, the gasifiers deliver to the BESS a gross total of 259 MWh distributed at 58% and 42% to charging column 1 and 2 respectively that leads to an average utilization factor of the HPCs equal to 14%. The biomass consumed annually is equal to 298 tons which lead to the co-production of 14.3 tons of biochar. Given these results, the economic analysis returned a payback time of 6.4 years considering a discount rate of 5% and up to 8.1 years considering a discount rate of 10% (Figure 5).

3.2 Results from life cycle assessment of electricity produced from vineyard prunings

The plot in Figure 6 presents the resulting carbon intensity of electricity produced from vineyard prunings, broken down by life cycle stage. The overall carbon intensity without the carbon credit amounts to 134 $gCO_{2e} \cdot kWh^{-1}$, with the pruning harvesting and pelletisation stages making up more than 90% of the emissions. Pelletisation is particularly emitting, due to the necessity to transport the pelleting machine on-field. In these respects, the solution featuring a centralised pelletisation plant in the area should be

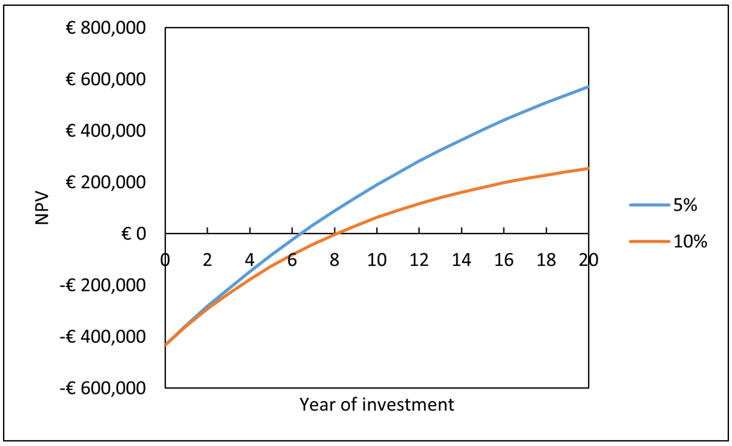

Figure 5: Payback time at 5% and 10% discount rates.

investigated in future studies. Nevertheless, emissions from this process are limited with respect to other literature studies [25], as biomass drying is performed without energy inputs. Transport activities weigh little towards the final amount. This is mainly due to the short transport routes inherent to the locally based solution under study.

It is noted that considering the carbon credit generated by the biochar sharply brings the carbon intensity of electricity below the zero threshold (-34 $gCO_{2e} \cdot kWh^{-1}$). This because for each kWh of electricity generated, almost 60 g of biochar are produced, that is equivalent to nearly 170 $gCO_{2e} \cdot kWh^{-1}$sequestered, considering a fixed carbon content of 80%. Negative carbon intensity can thus be obtained from the gasification process, although further analyses should include downstream emission related to the incorporation of biochar into the soil.

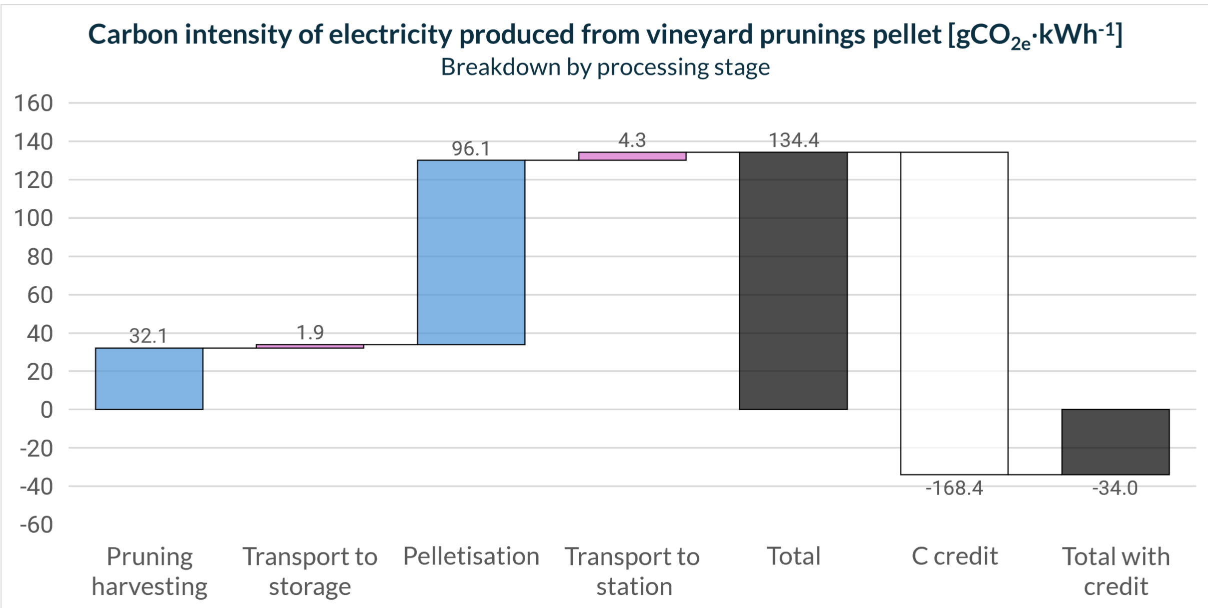

Figure 6: Breakdown of carbon intensity of electricity produced from vineyard prunings by processing stage.

Figure 7 shows the results of the sensitivity study on prunings yield and transport distances. Prunings yield shows the higher impact on electricity carbon intensity. Very low prunings yield, around 0.3 $t \cdot ha^{-1}$ would raise emissions by more than 50%, due to the relatively higher diesel consumption in the harvesting phase. On the contrary, variations of transport distance, together with the low contribution of this stage, weakly affect total carbon intensity. This remains valid only if the local nature of the solution is maintained and prunings are sourced within the vineyard district.

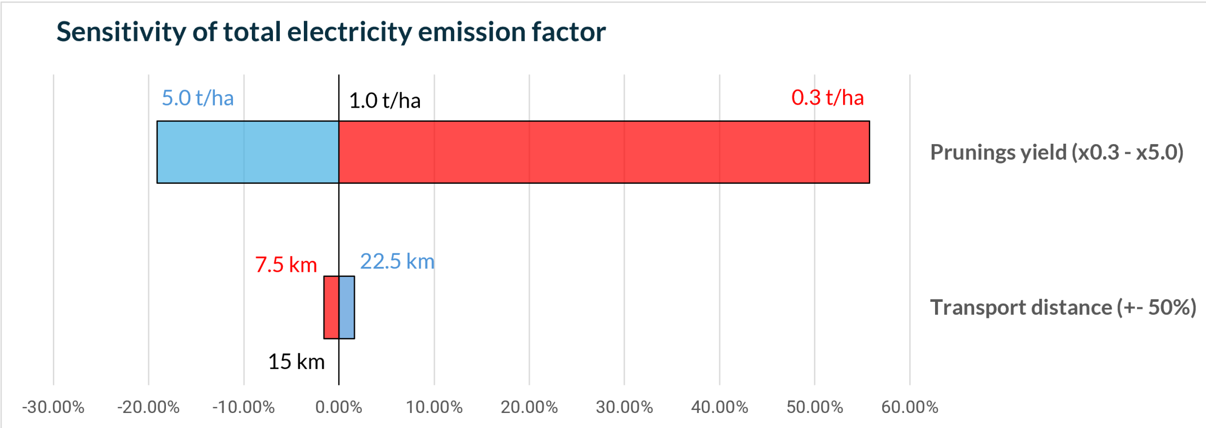

Figure 7: Sensitivity of carbon intensity of electricity produced from vineyard prunings (without carbon credit contribution) to prunings yield and pellet transport distance.

3.3 Comparison with specific emissions of electricity from the grid

The electricity emission factors obtained for biomass gasification can be compared to the performance of a reference EV charging system connected to the national electricity grid. To estimate the corresponding emissions, we have considered the weighted average of hourly emission factors in Italy (provided by a life cycle assessment of current and future electricity supply [38] for 2018 and 2030), adapted to the charging profile of this case study.

The resulting emission factor of the grid electricity for 2018 is equal to 384 $gCO_{2e} \cdot kWh^{-1}$, while the same figure for 2030 ranges from 141 $gCO_{2e} \cdot kWh^{-1}$to 226 $gCO_{2e} \cdot kWh^{-1}$depending on the future scenario that is considered. This comparison shows that under the assumptions presented above, the emissions related to the onsite electricity generation appear to be lower than the reference alternative of the grid electricity. However, considering the sensitivity analysis presented above, a reduced yield of 0.83 t/ha would make the emissions of the gasifier equal to 141 $gCO_{2e} \cdot kWh^{-1}$(which is the national grid emission factor in the best scenario), stressing the importance of the prunings yield. Furthermore, other countries may have lower electricity grid emissions, depending on their electricity mix. At the same time, a lower electricity carbon intensity would also decrease the emissions of the pelletisation stage, which is responsible for the lion's share of the emissions of the entire process. Thus, it is important to evaluate the performance of the system by taking into account the actual context in which it is deployed.

4 Conclusions

This study demonstrates that electricity production from vineyard prunings via gasification shows promising potential, particularly when considering the carbon credit from biochar production. The initial carbon intensity of 134 $gCO_{2e} \cdot kWh^{-1}$can be sharply reduced to -34 $gCO_{2e} \cdot kWh^{-1}$, indicating a carbon-negative process due to biochar sequestration. While challenges such as emissions from pelletisation and sensitivity to pruning yield exist, local sourcing minimizes transport impacts. These figures should be considered in the perspective of a reference weighted average carbon intensity of the national electricity mix that is currently equal to 384 $gCO_{2e} \cdot kWh^{-1}$, although it is expected to decrease in 2030 down to 141 $gCO_{2e} \cdot kWh^{-1}$-226 $gCO_{2e} \cdot kWh^{-1}$, depending on the future scenario that is considered.

Furthermore, integrating this technology into electric vehicle charging infrastructure proves economically viable with competitive energy sales prices and potential for carbon-negative energy labels. The analysis indicates that, for a charging price of 0.62 €kWh^{-1}, payback times range between 6 and 8 years depending on the discount rate considered.

However, the study's assumption of high utilization factor (14%) for the charging columns raises critical questions. This value, that was derived from estimates based on projected vehicle traffic and assumed behaviors of battery electric vehicle (BEV) drivers, significantly exceeds the actual national average (approximately at 3.2%), suggesting a need for robust validation against real-world data to assess feasibility accurately. Additionally, the expected charging profile, considered in this study, could be further compared to other actual charging profiles from real sites, that are not available at this stage.

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Abbreviations

Abbreviation	Definition
BESS	Battery Energy Storage System
BEV	Battery Electric Vehicle
CO_e	Equivalent carbon dioxide emissions
CHP	Combined Heat and Power
LCA	Life Cycle Assessment
NPV	Net Present Value
PB	Payback time
PHEV	Plug-in Hybrid Electric Vehicle
REDII	Renewable Energy Directive (2018/2001)

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