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Environmental Perspective of Decarbonization Actions in the Italian UNESCO Site of the Vineyard Landscape of Piedmont Region

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ABSTRACT

The current EU regulatory framework is forcing the need for a substantial and significant reduction of greenhouse gas emissions in all the main economic sectors since climate change effects are being more tangible in recent years. The adoption of actions and measures to reduce CO_2 emissions are thus essential for preventing global warming. For this reason, a simplified bottom-up approach is presented here to estimate the potential environmental benefit achievable, in terms of CO_2 emissions saving, when a set of proposed energy efficiency measures were adopted in relevant economic sectors of the UNESCO area of Vineyard Landscape of Piedmont Region in Italy.

Specifically, representative case studies where assumed for each economic sectors being studied to identify the energy efficiency measures to be adopted. Then progressive scenarios with different territorial diffusion of the proposed measures were performed

The analysis shows that a CO2 emissions reduction from 7.1% to 32.4% can be potentially obtained by considering different diffusion pathways of the identified energy efficiency measures in the residential, accommodation, private transport and

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food industry sectors, so that the UNESCO area can effectively contribute to contrast global warming. The proposed simplified approach can be replicated in other similar context to obtain rough estimation of emissions savings due to a territorial diffusion of energy efficiency measures considering available regional and local databases.

KEYWORDS

Bottom-up approach; Energy efficiency; Environmental benefits; Private economic sectors; CO_2 emission savings

1. Introduction

Climate Change is one of the greatest challenges of the future. The need of contrasting greenhouse gas emissions is perceived as an urgent subject by the world of research as well as by policymakers and public opinion (IPCC, 2021). This is particularly true in the European Union (EU) where four of the main economic sectors have a significant impact in terms of carbon emissions. The energy supply, transport, residential and agriculture sectors account in fact for around 80% of the whole CO_2 emissions in the EU (EEA, 2021).

On the one hand, specific actions can be implemented at the national/regional level in line with the ones proposed in the Paris Climate Agreement (UNFCCC, 2015) or in the European Green Deal (European Commission, 2020), for achieving either reduction of greenhouse gas (GHG) emissions up to 55% by 2030 or the carbon neutrality in EU. On the other hand, local actions, such as corporate missions on energy supply and management, can be adopted to improve social awareness and responsible behavior (Tavakolifar et al., 2021). Some examples are the production of energy (e.g. electricity and heat) from renewable energy sources (RES) and the adoption of Information Technologies (IT) for the digitalization of energy processes and their monitoring (Balogun et al., 2020; Kang et al., 2020).

In this context, all sectors of the society are hence committed for defining a system of carbon management aimed at identifying and implementing those measures economically efficient to reduce CO_2 emissions by using low-carbon technologies or through measures aiming at compensating the GHG emissions (e.g. planting of trees, renewable energy production, waste reduction, etc.). In this view, a wider literature exists promoting the adoption of decarbonization actions in different economic sectors considering different spatial/territorial resolutions. Basically, in most of the studies, the general idea is to estimate the energy demand and the corresponding GHG emission of one or more economic sectors, in a given area or country, and then evaluate how decarbonization actions can reduce energy consumption and emissions. Two different methodological approaches can be observed: a first one based on aggregated data, where National energy demand is used as input, so CO_2 emissions reduction are calculated as a consequence of the reduction in energy consumption due to the energy efficiency measures; a second one adopting a bottom-up approach where energy demand is evaluated considering average "case studies", so the aggregated territorial consumption and emissions are calculated as a replication of the reference use cases.

The approach based on aggregated data is, for instance, considered in (Sofia et al., 2020) where the Italian energy, transport and household sectors have been studied to exploit the future deployment of RES production, the electrification of public and private transport, the diffusion of heat pumps and the energy retrofit of residential buildings envelope. This cost-benefit analysis, compares investment costs for introducing these mitigation strategies with the achievable external cost saving related to lower emissions, which are estimated in a range of 40% to 70%. Similarly, the study presented by (Lund et al., 2022) analyzed the introduction of a national action plan in Denmark where the promotion of RES production, the electrification of energy consumption and the increase of energy efficiency in buildings are considered to decarbonize the energy (heating, cooling and electricity), the industry and the transport sectors. In this case, by still using aggregated national data, the implementation of a Smart Energy plan would lead to a 100% renewable energy transition in 2045.

Otherwise, bottom-up approach is considered in other studies. For example, the one presented by (Clora and Yu, 2022) investigates different decarbonization pathways for the economic sectors of the EU adopting a bottom-up approach based on the EUCalc model (Pestiaux et al., 2019). On the one hand, the model estimates the energy demand of the different end-use services (e.g. buildings, transport, etc.) considering average and reference people's lifestyles, demographic evolution and technological trends in the EU.

On the other hand, the model calculates the energy production need to supply the demand and the consequent GHG emissions, so that, for instance, changes in reference technology evolution and diffusion as well as in lifestyle can be compared for different decarbonization pathways: emission reductions between 32% and 66% can be achieved in 2050 considering thirty-one potential pathways. Moreover, the potential benefits due to the use of hydrogen in different economic sectors (i.e., industry, residential building, transport and energy) of the EU are explored by (Seck et al., 2022) based on three different models: a detailed bottom-up model using linear programming to minimize the costs of the EU energy systems; an aggregated energy system model for Europe to identify optimal investment strategies for achieving CO_2 emissions reduction targets; a supply chain optimization model of hydrogen with high spatial and temporal resolution. In all these approaches, assuming pathways for the diffusion of hydrogen as well as for RES technologies, the former can effectively contribute in reaching EU carbon neutrality in 2050.

Although all these works consider the synergy of decarbonization actions in different economic sectors, typically at a large territorial scale, other studies based on bottom-up approach are instead focused on specific sectors. For instance, the decarbonization of the energy consumption in the residential sector in Japan is instead studied by (Shimoda et al., 2021): different decarbonization scenarios have been evaluated adopting a bottom-up simulation model where the energy consumption in Japanese residential buildings is estimated considering, among others, reference building typologies, end-users behavior and household composition. The progressive adoption of energy efficiency in buildings (including PV installation and thermal insulation) as well as the electrification and the energy efficiency of equipment and home appliances, may contribute to a drastic reduction of primary energy consumption up to 61% capable to achieve almost net zero carbon emissions. Moreover, (Obrist et al., 2022) investigated the decarbonization of a reference Swiss pulp and paper industry through a techno-economic bottom-up optimization model capable to estimate energy demand and production in different technological scenarios (e.g., with RES production). The analysis shows that, by replicating the adoption of energy efficiency measures, the whole Swiss pulp and paper industry sector could reduce its energy consumption by

32% and achieve net-zero CO_2 emissions by 2050 with electrification of the heat supply. Additionally, also reduction of greenhouse gases emission can be gained in agriculture sector. For instance, carbon capture is considered in (Tezza et al., 2019) where the CO_2 soil uptake can be increased up to 45% by a soil management on a vineyard use case based on cover crops. CO_2 sequestration from alcoholic fermentation is proposed in (Marchi et al., 2018), where around 8% of CO2 can be reused in production activities to reduce the use of gas produced by industries from industrial process based on fossil fuels.

Notwithstanding this literature investigated the main economic sectors, also the cultural heritage can significantly contribute in reducing the carbon emission, as remarked by UNESCO through the promotion of renewable energy installations in all the regions of the World Heritage Convention (UNESCO, 2022) as well as the diffusion of knowledge for contrasting Climate Change (UNESCO, 2017). In this view, literature investigated the opportunity offered by the implementation of decarbonization actions in some of the UNESCO sites. The introduction of using solar energy in buildings, the improvement of buildings envelope and the use of RES in space heating are evaluated, for instance, within the National Park and UNESCO site of the Cinque Terre in Italy (Franco, 2018). The energy retrofit of the Olivetti office building in the UNESCO site of Ivrea (Italy) is instead presented in (Galbiati et al., 2021) to reduce energy consumption up to 55%, through the increase of thermal insulation, preserving the historical and cultural value of the site. Moreover, the energy optimization of the urban transport fleet in the city of Ávila, within the World Heritage Sites of Castile and Lion, is analyzed in (Santos-Iglesia et al., 2022) to exploit regenerative breaking systems to recover almost 70% of the wasted energy.

However, all these studies are limited to the adoption of specific solutions within a small territorial scale. Moreover, the synergy of different economic sectors (e.g. residential and industrial) is not considered within these UNESCO sites as well as any methodology, according to the aforementioned literature, is considered to estimate the reduction in energy consumption and carbon emissions at territorial level due to the adoption of specific decarbonization actions. Recently, the study presented by (Matos and Pirra, 2022) tried to overcome these limitations by investigating the CO_2 emissions related to the wine production within the UNESCO site of the Alto Douro Wine Region, but the study is not strictly focused on the identification of potential measures to decarbonize the site, so that also the interaction of different economic sectors is not considered.

For all these reasons, since cultural heritage UNESCO sites can potentially include also different economic sectors, this paper presents a simplified approach developed for investigating the potential GHG emissions reduction achievable within the UNESCO Vineyard Landscape of Piedmont, which involves an area of 16 municipalities within the Cuneo province in the North-West part of Italy. This simplified approach, similar to other studies, estimates the potential reduction of carbon emissions due to different adoptable measures and actions in different economic sectors. Clearly, the methodology adopted is based on a *"bottom-up"* approach because aggregated data are not typically available at a small territorial scale, while reference and representative use cases can be easily identified. Although the UNESCO classification of the studied area is focused on wine and vineyard landscape, the economic sectors considered in this study are not only related to wine activities. In fact, as considered in other above-mentioned studies adopting a bottom-up approach, all those sectors which are economically relevant for the area being studied should be taken into account. So the analysis is performed by identifying reference case studies for each relevant economic sector where the measures can be implemented. Subsequently, economically feasible decarbonization actions were identified for each case study, considering also local regulatory limitations preserving cultural heritage site. Then, the resulting emission savings are territorially spread by using available local datasets.

The rest of the paper is organized as follows: the description of the simplified bottom-up methodology is presented in Section 2, the reference case studies for different economic sectors are presented in Section 3 as well as the energy efficiency measures and the corresponding estimated emission savings; finally, the methodology to spread the emission savings across the UNESCO area and the results of the aggregated CO_2 savings at the territorial level are instead presented and discussed in Section 4.

2. Methodology

The main goal of this study is to estimate the environmental benefits deriving from the reduction of energy consumption through the diffusion of decarbonizing measures on a large territorial scale. In particular, the high fossil fuels consumption in all the main economic sectors is the main responsible for the yearly CO_2 emissions (Iorio and Federici, 2021; Ministry for the Environmental Land and Sea, 2019a) and the global warming issues. Hence, proper strategies are of interest in nowadays society to increase the renewable energies share and energy efficiency to prevent climate change phenomena. In this context, stakeholders of the private sector play a crucial role to promote and increase the adoption of sustainable technologies in their territories also supported by the local authorities. For this reason, as observed in other cases (Prina et al., 2020; Sanchez-Escobar et al., 2021), the simplified bottom-up approach adopted in this paper starts with the identification of the economic sectors whose activities are considered territorially relevant and representative from the energy and economic point of view. This selection is fundamental since different contexts could have different key sectors representing their local economic framework.

The area selected to apply the simplified approach is part of the UNESCO Vineyard Landscape of Piedmont (UNESCO, 2014). This landscape covers five wine-growing areas located in the southern part of Piedmont, between the Po River and the Ligurian Apennines, where winegrowing and winemaking has characterized the region for centuries. The studied area involves 16 municipalities of the Cuneo province, in the North-West part of Italy (see Figure 1), that devoted particular attention to environmental issues during the last years. Within this UNESCO area, the following sectors were considered according to the longstanding vocation of the area in the food, wine and touristic fields: wine, hospitality, residential building, small and medium enterprise (SME) in the local food chain, and the private transport. In particular, the area of Figure 1 approximately host 295 accommodation facilities (including hotels and Bed&Breakfasts) (Ente Turismo Langhe Roero Monferrato, 2020), 390 wine-growing and wine-making facilities covering an area of about 5360 hectares (Consorzio di Tutela Barolo Barbaresco Alba Langhe e Dogliani, 2021), 18250 residential buildings (Regione

Piemonte, 2020a), 800 companies in the food and beverage sector (Italian National Institute of Statistics, 2020), and around 37400 passenger cars related to the private mobility (ACI, 2019). This current picture, as in-depth analyzed in Section 4.6 by implementing the proposed approach, corresponds to a yearly CO_2 emissions approximately equal to 683.1 $GgCO_2$ which is less than 0.2% of the whole National emissions estimated in 2022 (Crippa et al., 2022).

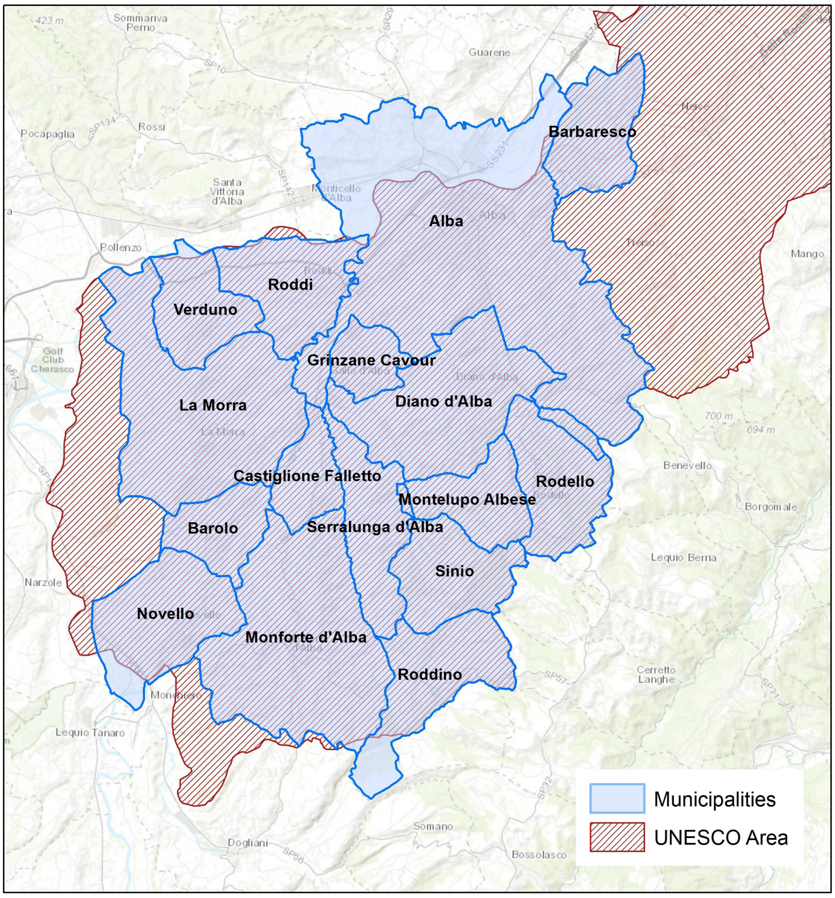

Figure 1. The studied area within the UNESCO site.

Each of the identified economic sector is then linked to a representative pilot case, that must be chosen according to the specific characteristics of the area being studied. The selected use cases have been directly used as references to estimate the energy and emission savings according to the proposed decarbonization measures. Their economic feasibility is also briefly investigated for ensuring potential replicability within the studied area. After, CO_2 emission reductions are spread across the whole UNESCO area as a territorial replication of the proposed decarbonization actions of the pilot cases. The diffusion of these actions and the corresponding environmental impacts were extrapolated considering the current available territorial datasets as depicted in Figure 2. In fact, from these local datasets, information on the diffusion of the use cases being studied is available. Thus, the emission savings of each single reference case study is proportionally spread on a larger territorial boundary. Practically, the yearly energy saving and emission reduction estimated in each pilot case are supposed to be replicated in other similar use cases identified through data extracted by territorial datasets. This means that, once the carbon savings are estimated in the representative case studies, the datasets are used to estimate, at the territorial level, the number of similar situations where the decarbonization actions can be opportunely replicated. Clearly, this static approach (Després et al., 2015) uses energy and environmental outcomes of the pilot cases in a given target year, so the calculated benefits are supposed to be kept also in the future. Moreover, the simplified approach proposed here is not developed from a LCA perspective, so only the GHG emissions related to the energy consumption in the pilot cases are considered.

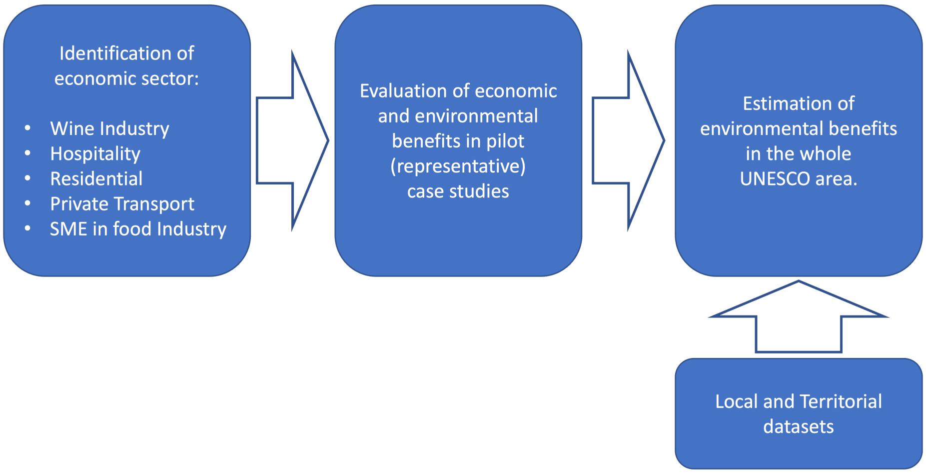

Figure 2. The simplified bottom-up approach adopted for the UNESCO site.

2.1. Limitations

As already claimed, the simplified bottom-up approach proposed here is based on the identification of use cases whose replicability is territorially spread over the UNESCO area being studied. The impact of suggested energy efficiency measures is evaluated at a single representative case study and then spread on the studied area considering the diffusion of the use case. This evaluation is performed under the assumption that all the use cases on the area have the same characteristics of the reference ones.

Of course, this approximation leads to less accuracy in evaluating the impact of the decarbonization actions. Nevertheless, more detailed data are not often available and, even if they are accessible, data are not always complete and tractable. In contrast, the proposed simplified approach can be generalized enough and the results, although approximated, give a first estimation of the environmental impact due to the implementation of a set energy efficiency measures in different economic sectors diffused on a territorial context.

3. Case studies

In the following Sections, the reference case studies considered in this work, the adopted measures and the corresponding environmental impact are described in detail. The set of potential measures to be selected include the use of biomass, Combined Heat and Power (CHP), photovoltaic (PV) and the use of electric vehicle (EV). Such interventions have been selected depending on the energy vectors demanded by the use case (e.g., heat and/or electricity) and how the energy consumption is distributed over a year. For instance, case studies with relevant consumption of heat and electricity across the whole year, will lead to the adoption of CHP units ensuring higher economic refund of the investment.

Additionally, for some of the proposed measures such as PV, limitations on the way these systems can be installed has been considered. For instance, a local resolution of the Piedmont Region prohibits the installation of ground-mounted PV system in agricultural area or areas subjected to the protection of the landscape and of the historical, artistic and cultural heritage (Regione Piemonte, 2010). As a consequence, only building integrated PV systems were assumed.

3.1. Winery

The first case study analyzed was a winery, located within the UNESCO area, with a yearly production of almost 2.3 million wine bottles. The thermal demand for space heating and domestic hot water is currently satisfied through two conventional boilers fuelled by diesel and a liquefied petroleum gas (LPG) with an estimated efficiency of 80% and 90%, respectively. The fuel yearly consumption of these boilers is around 12000 l and 2400 l, corresponding to a heating demand of around 111.7 MWh, with an average per unit cost of 0.95€/l and 0.65€/l for diesel and LPG, respectively. The yearly electricity demand is instead close to 555.6 MWh with a measured average per unit cost of 0.18 euro/kWh.

From this data, yearly emissions of 35.4 tCO_2 and 158.1 tCO_2 were estimated due to thermal and electricity demand, respectively. This result is based on the emission factors currently available for different energy vectors in Italy, as reported in (ISPRA, 2019; Ministry for the Environmental Land and Sea, 2019b). In particular, an emission factor of 284.5 tCO_2/kWh was considered for the electricity bought from the grid, while emission factors of around 0.00157 tCO_2/l and 0.00263 tCO_2/l were assumed for LPG and diesel, respectively. These estimated emissions, following the criteria adopted in (Vassilis et al., 2020), have been then normalized with respect to the yearly production of wine bottles, so that an indicator of 84.5 gCO_2/bottle is obtained as a benchmark for the whole winery sector in the area.

According to the current energy demand, two integrated measures have been proposed for this case study:

- The installation of a biomass boiler to cover 80% of the thermal demand by taking advantage of the wood availability around the UNESCO area. In this case, a net-zero balance of CO_2 emissions (Cătuţi et al., 2020) can be considered for biomass to drastically reduce the environmental impact of the hot water demand.
- The integration of a photovoltaic (PV) plant with an installed capacity of 229 kWp to exploit an available surface of 1600 m^2 taking into account an occupancy rate of 7m^2/kWp (Ali and Khan, 2020). According to the estimated yearly PV

production and the current energy demand available for this case study, the PV plant can cover around 51% of the electricity consumption with an assumed self-consumption of 100% (i.e. no grid injection is expected).

An overall investment cost of 230 k€has been estimated (assuming a PV capital cost of 1000€/kWp (Energy and Strategy Group, 2018)) for the proposed measures with a discounted payback period of around 8 years (considering PV maintenance cost of 45€/kWp/year (Energy and Strategy Group, 2018)) Instead, the estimated environmental benefits deriving from the above-mentioned measures can be observed in Table 1.

Table 1. Simulation results for wine production case study

	Current Emission (tCO_2/year)	Estimated Emission (tCO_2/year)	Variation
Thermal demand	35.39	5.9	-29.5 (-83.3%)
Electric demand	158.08	76.77	-81.29 (-51.4%)
Total	193.45	82.67	-110.8 (-57.3%)

The adoption of a biomass boiler and a PV plant is thus capable to massively reduce the environmental impact of the winery from 84.5 gCO_2/bottle to 36.13 gCO_2/bottle, with an overall decrease close to 60%. This result is, of course, due to both measures having a high impact in terms of emission reduction. Biomass is in fact assumed as a carbon neutral energy source and, similarly, PV production does not directly emit greenhouse gasses.

3.2. Accommodation facility

The second case study concerns a hotel, whose area is split into the main accommodation facility of 3290 m^2 hosting 72 beds, and the other 950 m^2 for a wellness/relax area. A 90% efficient boiler fuelled by LPG is used to cover a yearly thermal load close to 1300 MWh for both facilities with a yearly demand of 157000 l and 67500 l for the accommodation facility and the wellness/relax area, respectively. A yearly electricity consumption of about 1.2 GWh was instead observed in this case study. The energy cost of the accommodation facilities was equal to 0.36€/l for LPG, while the per unit electricity cost was approximately close to 0.16€/kWh.

A preliminary analysis of the hourly based thermal and electric load profiles detected how the minimum and the peak electricity demand of about 80 kW and 265 kW can be observed in this pilot case. While a minimum and a peak thermal demand of 75 and 300 kW is observed for hot water production. In this case, it is noticeable that the minimum power demand of the electric and thermal load profiles results to be relatively high if compared to the peak demand. This condition is favorable for the installation of a Combined Heat and Power (CHP) plant to produce both electricity and heat that can be self-consumed by the facility (Kalina and Skorek, 2006). This condition is in fact attractive from a technical and economical point of view, since the CHP can operate for many hours at rated power during the year ensuring higher profitability.

For this reason, the installation of a gas-fired CHP is the measure identified for this case study. However, two different options have been explored considering two different gas-fired CHP sizes: the first one with rated electric and thermal power of 100 kW and 112 kW, respectively, and a more powerful engine with 160 kW electrical power and 168 kW thermal power. Both options were analyzed assuming two different scheduling strategies:

- Follow-electric: CHP operates at partial load ranging from 50% to 100% of its rated power depending on the electric load.
- Full-throttle: the CHP always operates at rated power when switched on, regardless the thermal or electric loads.

However, in both cases, CHP is supposed to be switched off when the electric load is lower than the minimum load factor (i.e. 50%) (Freschi et al., 2013) to preserve CHP technical lifetime.

The technical and economic analysis relied on all of the four scenarios obtainable by mixing different scheduling strategies and sizes of the CHP plant. In particular, capital and maintenance costs of 2000€/kWe and 0.015€/kWh were assumed for the CHP, respectively (Duffy et al., 2015). Primary Energy Saving (PES) and Energy Utilization Factor (EUF) were also evaluated, since these indicators were used to estimate the potential subsidies granted for CHP plants filling the requirements of the current Italian regulatory framework (GSE, 2019) (e.g. natural gas tax reduction).

The environmental benefit was finally evaluated considering the emission factors currently available for different energy vectors in Italy (ISPRA, 2019; Ministry for the Environmental Land and Sea, 2019b). In particular, a CO_2 emission factor of 0.00157 tCO_2/l was considered for the LPG, while an emission factor of 284.5 tCO_2/kWh and 202 tCO_2/kWh was considered for the electricity from the grid and the natural gas used to feed the CHP, respectively. Accordingly, a baseline scenario of 1105 tCO_2 per year emitted by the LPG boiler and the electricity from the grid was estimated. Similarly to the winery case study, these estimated emissions have been then normalized with respect to available beds in the accommodation facility, so that an indicator of 15.4 tCO_2/bed is obtained as a benchmark for the whole hospitality sector.

Table 2. Simulation results for hotel case study

	PES (%)	EUF (%)	Current Emission (tCO_2/year)	Estimated Emission (tCO_2/year)	Variation
100 kWe full throttle.	23.96	81.4	1105.3	821.2	-284.1 (-25.7%)

Table 2, shows the energy and environmental results obtained for the most profitable configuration where a CHP unit of 100 kW size, fueled by natural gas, is installed. In fact, according to the economic analysis, this measure has a faster discounted pay-back period of the investment (about 3 years) with more than 8000 hours per year of operation. The adoption of a CHP unit with full throttle management will reduce environmental indicator from 15.4 tCO_2/bed to 11.4 tCO_2/bed, with an overall decrease close to 26%, in line with expected emission savings for this end-user typology (Mago and Smith, 2012) adopting cogeneration.

3.3. Residential building

The third pilot case presented in this paper is focused on a multi-family building located within the UNESCO area, whose thermal demand for space heating is satisfied by means of District Heating (DH) network. This building, like the others within the UNESCO area, is not classified as historical one, so no particular differences or restrictions exist with respect to buildings in other residential area. The building has a gross volume of about 2520 m^3 (the net heated volume is instead equal to 1890 m^3) and a gross floor area of about 210 m^2. The average yearly thermal demand observed in the last three years is instead around 60.6 MWh. In this case study, only space heating consumption is considered, while the electricity demand is neglected due to the difficulties of adopting specific action to mitigate its carbon impact. In fact, even if PV installation can represent a suitable measure, the diffusion of this technology in multi-family buildings is still weak because of uncertainty in the local and national regulatory framework (RSE, 2022) leading to administrative delays.

Since DH efficiently provides thermal energy (Corradi et al., 2021), no measures have been evaluated regarding the substitution of the heating system. However, even if a conventional boiler (i.e. based on fossil fuel) was installed, the substitution of the heating system was not still considered since high efficiency natural gas boilers are already present in most of the Italian multi-family buildings (Bianco and Marmori, 2022). Conversely, energy efficiency measures improving the building envelope were evaluated, since the construction period of the residential building is around the 1970s and the reduction of thermal losses is a priority in the Italian context where building stock, whose average age is high, suffers of scarce thermal insulation (Italian Ministry of Economic Development, 2017).

The reduction of thermal energy demand through envelop improvements were based on the following two main measures, widely considered in previous studies (Amirkhani et al., 2021; Choi et al., 2022):

- The opaque surfaces can be equipped with insulating material to prevent heat losses. In particular, insulation can be improved for the main vertical walls by means of the introduction of either external coating or internal air cavities filled with material such as foam.
- The transparent surfaces can be replaced with more efficient glazing systems.

Thermal characteristics and thicknesses of both opaque and transparent surfaces as well as internal spaces subdivision, walls surfaces and each floor's height have been estimated using the construction period as reported in (Corrado et al., 2014). In particular, Table 3 reports the thermal transmittance estimated and adopted for modeling the opaque and transparent surfaces of this pilot case study. While Table 4 reported the limits to be respected for the thermal transmittances in the current Italian framework (Governo della Repubblica Italiana, 2020b).

Table 3. Envelop characteristic of residential pilot case study (Corrado et al., 2014)

	Thermal transmittance (W/m^{2}K)	Thickness (cm)
Upper horizontal opaque surface	1.632	33
Lower horizontal opaque surface	1.31	35.5
Vertical opaque surface	1.22	34
Transparent surface	5.1	0.3

Table 4. Regulatory limits of thermal trasmittance (Governo della Repubblica Italiana, 2020b)

	Thermal transmittance (W/m^{2}K)
Horizontal opaque surface	0.25
Vertical opaque surface	0.23
Transparent surface	1.3

Two different refurbishment scenarios were investigated with two different approaches adopted for the opaque surfaces, while only one replacement option was considered for the transparent surfaces. Scenario A refers to the building envelope insulated by means of an external layer, while in Scenario B external walls have been internally insulated with foam and lately with additional external layer to satisfy legislative constraints. In particular, the new thermal characteristics and thicknesses of both opaque and transparent surfaces were selected in order to be compliant with the requirements of the Italian regulatory framework in Table 4.

The simulation of both scenarios reported an almost identical reduction in energy consumption, and hence in CO_2 emissions close to about 64% (see Table 5) considering the emission factors for DH extracted from (Ministry for the Environmental Land and Sea, 2019b). Clearly, this relevant reduction of carbon emissions of around 32tCO_2 is also influenced by the preexisting condition of the energy demand due to the scarce thermal insulation of the case study.

Table 5. Simulation results for residential case study

	Thermal demand (MWh/year)	Variation
Scenario A	21.7	-64.1%
Scenario B	21.4	-64.7%

The proposed measures are generally recognized as costly for residential buildings (Amirkhani et al., 2021), and the investment of the proposed measures can be estimated in approximately 320k€ (Ministry for Ecological Transition, 2021). However, the Italian context offers fiscal incentives to promote the adoption of these solutions. In fact, these refurbishment measures can also benefit of the current Italian incentive scheme named *"SuperBonus"*, where a tax deduction of 110% of the capital cost needed for the energy retrofit of the building can be spread over 5 years (Governo della Repubblica Italiana, 2020a). This benefit makes the measures economically more attractive and sustainable, since all the investment costs can be recovered in a relatively short period. However, tax deduction can be obtained only if the energy retrofit measures ensure an improvement of at least two classes of the building energy efficiency rating. In this case, the simulation shows how it could be possible to improve the current rating (i.e. G class) up to class D, making the measures economically profitable.

3.4. Local SME in the food chain

Another sector considered in this study is represented by a local Small and Medium Enterprise (SME) whose activities are involved in the food production chain, where 1,000 tons of products per year are delivered. A natural gas boiler of 3MW with 90% efficiency is used to produce 1.85 GWh/year of heat for industrial processes, while about 1.7 GWh of electricity is annually consumed representing about 80% of the energy costs for the SME. Electricity and natural gas per unit costs were instead estimated close to 0.17€/kWh and 0.37€/m^3, respectively.

An analysis of the electric load profile revealed a peak demand of 500 kW and an almost constant base load of around 100 kW for about 8000 hours per year. As already observed for the accommodation facility in Section 3.2, this relatively high base-load leads to the possibility of installing a CHP plant to produce both electricity and heat that can be self-consumed by the SME. Additionally, a roof with an available area of 1,300 m^2 could be potentially used to install a PV plant.

Consequently, two energy-saving measures were investigated according to the characteristic of this industrial facility:

- The installation of a gas-fired CHP unit with an electric and thermal rated power of 160 kW and 168 kW, respectively. Two possible management strategies of the CHP operations have been considered (i.e. Electric-follow and Full-throttle), as for the accommodation case study.
- The installation of a 50 kWp PV plant has been assumed on the 1,300 m^2 unused roof to increase RES production and self-consumption.

Table 6 shows the energy and environmental benefits of the most profitable configuration formed by a PV plant and a CHP unit managed with full throttle operation. Of course, the energy production by PV reduces the electricity cost, while no direct CO_2 emission occurs. On the other hand, cogeneration contributes to the reduction of primary energy consumption (i.e. in PES) with corresponding emission savings, since CHP has a global efficiency typically higher than the separated electricity and heat productions (Spentzas, 2009). This is particularly true in this case study where both electric and thermal base loads are quite high and energy is required almost constantly across a year. Moreover, the suggested configuration ensures a short payback period of slightly more than 2 years years for the CHP investment by assuming capital and maintenance costs of 2000€/kWe and 0.015€/kWhe, respectively (Duffy et al., 2015)). While a longer payback period of around 10 years is expected for the PV plant due to its higher investment cost (i.e. around 1200 €/kWp (Energy and Strategy Group, 2018)).

Starting with a baseline emission of 1460 tCO_2/year, calculated by means of the emission factors of natural gas and electricity adopted for the other case studies (ISPRA, 2019; Ministry for the Environmental Land and Sea, 2019b), the proposed configuration can potentially reduce CO_2 emissions down to 1028.5 tCO_2/year by combining both CHP and PV benefits, with corresponding emissions saving close to 30%.

Table 6. Simulation results for SME case study

	PES (%)	EUF (%)	Current Emission (tons/year)	Estimated Emission (tons/year)	Variation
160 kWe full throttle	27.2	84.1	1460	1028.5	-431.5(-29.6%)

3.5. Private Transport

The last sector considered in this study refers to private mobility. Currently, around 37400 passenger cars circulate within the studied area (ACI, 2019). According to the available data, cars fueled by gasoline and diesel represent 92% of the whole circulating fleet, while only 6.7% and 0.3% of passenger cars are fueled by LPG and natural gas, respectively. Hybrid electric vehicles (HEV) are instead still a marginal portion accounting for less than 1% (see Table 7)

Table 7. Distribution of passenger cars by fuel in the UNESCO area (ACI, 2019)

Gasoline (%)	LPG (%)	Natural Gas (%)	Diesel (%)	HEV (%)
42.7	6.7	0.3	49.4	0.9

In this context, a future scenario has been assumed where the private transport sector will use a solution with lower environmental impact and reduced emissions such as the Battery Electric Vehicle (BEV) (Rahman et al., 2021). The electrification of private transport can in fact offer a valuable opportunity for reducing GHG emissions (Besagni et al., 2021). The specific CO_2 emissions reported in Table 8 for different fuels show a considerable potential reduction of around 48% shifting from gasoline to electric vehicle (BEV) and a reduction of around 51% shifting from diesel to EV. Clearly, even if direct CO_2 emissions are avoided by BEV, the specific value in Table 8 includes all those due to the electricity bought from the grid and used to feed EVs which is still mainly produced by fossil fuels in the Italian framework (IEA, 2019).

Table 8. Specific CO_2 emissions for passenger cars by fuel (ISPRA, 2021).

Gasoline ($kgCO_2/km$)	LPG ($kgCO_2/km$)	Natural Gas ($kgCO_2/km$)	Diesel ($kgCO_2/km$)	HEV ($kgCO_2/km$)	BEV ($kgCO_2/km$)
0.1626	0.1577	0.1768	0.1707	0.0969	0.0844

Of course, the economic profitability of using an EV has been also performed by comparing the Total Cost of Ownership (TCO) with the one of a conventional vehicle equipped with an internal combustion engine (ICE). The analysis was performed by implementing the methodology adopted in (Energy and Strategy Group, 2020) and comparing two commercially available vehicles of the same market segment (i.e. the B segment) and assuming a yearly average traveled distance of around 11000 km for

Table 9. Data considered for the TCO comparison.

	Renault Clio (ICE)	Renault Zoe (BEV)
Price (including incentives and charging infrastructures)	21000€	28100€
Consumption	5.3 l/100km	13.2 kWh/100km
Fuel price	1.6 €/l	0.2 €/kWh
Maintenance	500 €/y	150 €/y
Assurance	500 €/y	350 €/y
Taxes during the first five years	180 €/y	0 €/y
Taxes from the sixth years	180 €/y	45 €/y

Italian passenger cars (Lazzeroni et al., 2021). The data considered for the comparison are reported in Table 9 which include both recurring costs (e.g. fuel, maintenance, etc.) and one-time costs (e.g. purchase, etc.) as well as Italian incentives for EVs.

The analysis highlights how the TCO of a BEV becomes comparable to the one of an ICE after 5-6 years of lifetime considering domestic charging, as confirmed by (Energy and Strategy Group, 2020), making the EV the choice of the future for the decarbonization of the private transport sector.

4. Results

After the identification of the measures for the reduction of GHG emissions in the representative case studies, the simplified approach described in Section 2 has been applied to spread the CO_2 emissions reduction within the studied territory. Thus, for the sake of simplicity, in the proposed approach the average emission and energy savings calculated for a specific case study are supposed to be the same for the whole represented sector. Consequently, once the number of contexts where the energy efficiency measures can be replicated is identified, by means of an analysis of regional database, the whole savings of a sector can be calculated in the UNESCO area represented in Figure 1.

Table 10 summarises the main decarbonization measures identified for the different economic sectors considered in this study. It can be noticed, how both active and passive measures have been supposed to be adopted in the area. In particular, RES generation and energy efficiency are the most relevant measures assumed to reduce carbon emissions. In this perspective, Biomass ensures net zero carbon emissions, PV doesn't produce environmental externalities while producing electric energy, while

CHP, EV and energy retrofit are solutions capable to increase energy efficiency and, thus, reduce primary energy consumption and then CO_2 emissions.

Table 10. Decarbonization measures identified for the economic sectors.

Economic sector	Measures
Winery	Biomass boiler, PV
Accommodation facility	CHP
Residential buildings	Energy retrofit improving thermal insulation
Local SME	CHP, PV
Transport	EV

In the following Sections, the territorial impact of the decarbonization actions adopted for each case study is evaluated and, finally, the aggregated results are also presented and discussed.

4.1. Winery

As presented in Section 3.1, the reduction of GHG emissions in the pilot case of a winery canteen was estimated considering the yearly production of wine bottles as a normalization factor. The proposed measures promote, in fact, a reduction of CO_2 emissions passing from the current 84.5gCO_2/bottle to 36.13gCO_2/bottle.

According to this carbon saving, the approach assumed to spread these results in the studied area is based on the identification of the yearly bottle production in the municipalities within the UNESCO site. In particular, the emission savings, as well as the CO_2 emitted before and after the potential implementation of the proposed measure, were then calculated by multiplying the per unit emission factors of the pilot case by the number of produced wine bottles in each municipality.

Thus, data concerning wine bottle production are fundamental to estimate the emissions savings. Figure 3 shows data extracted from the dataset of the Consortium for the Protection of Barolo Barbaresco Alba Langhe and Dogliani (Consorzio di Tutela Barolo Barbaresco Alba Langhe e Dogliani, 2021). The dataset reports how an overall yearly production of around 31.8 million wine bottles is distributed in each municipality of the UNESCO site.

Considering the results of Table 1, obtained for the representative case study, and assuming the same results for all the winery companies in the area of Figure 1, the

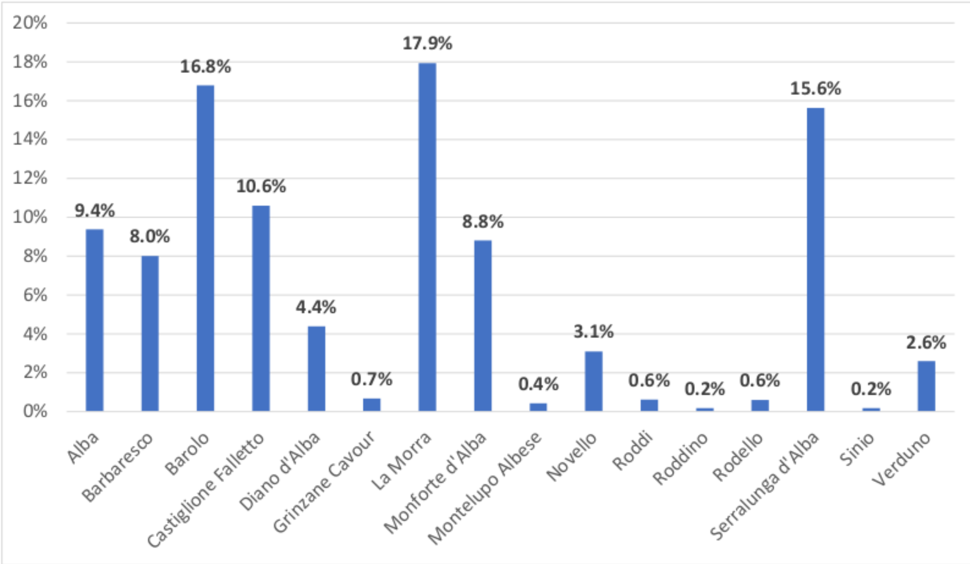

Figure 3. The yearly production of wine bottles by municipalities.

CO_2 emissions were estimated before and after the implementation of the proposed measures according to the production of wine bottle shown in Figure 3. It is noticeable how, for companies in the wine sector, the overall CO_2 emissions can be potentially reduced from around 2690 tCO_2/year down to around 1150 tCO_2/year, with a relative reduction of around 57% thanks to wider adoption of biomass and PV production. However, this reduction only concerns the energy consumption of the companies for the wine production, so it does not take into account other aspects like the one related to the production of packaging.

Finally, Figure 4 shows how the annual CO2 emissions savings are spread over the different municipalities: the higher reductions are clearly obtained in the municipalities with the highest wine production. This result highlight how the use of RES (i.e. biomass and PV) can be a valuable option for contributing to the reduction of carbon emissions within wine production as also pointed out in (García-Casarejos et al., 2018) from a carbon footprint point of view.

4.2. Accommodation facility

As already discussed in Section 3.2, the potential reduction of CO_2 emission for the hotel case study was estimated considering the number of available beds as a normal-

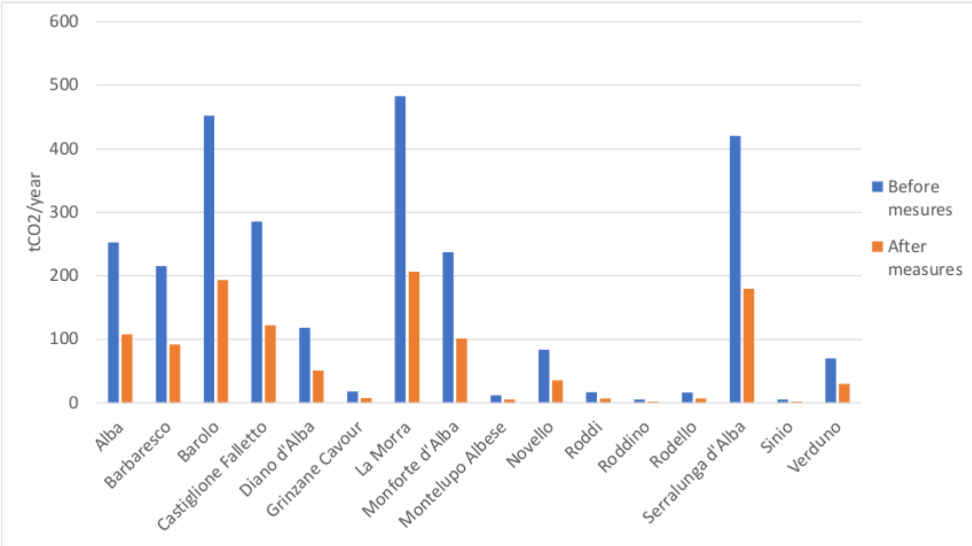

Figure 4. Yearly saving of CO_2 emissions for wine production by municipalities.

ization factor. The proposed measures promote, in fact, a reduction of CO_2 emissions passing from the current 15.4 tCO_2/bed to 11.4 tCO_2/bed in line with the expected values calculated for Italian hotels (Crespi et al., 2021). As for the wine sector, an approach based on available datasets is used to spread this result across the whole UNESCO area. According to the result presented in Section 3.2, the approach is based on the identification of the available beds in the hospitality sector within the UNESCO site. In particular, the emission savings, as well as the CO_2 emitted before and after the potential implementation of the proposed measure, were then calculated by multiplying the emission saving of the pilot case by the number of available hotel beds in each municipality.

An analysis performed on the data available from the Tourism Authority of Langhe, Roero and Monferrato (Ente Turismo Langhe Roero Monferrato, 2020) shows that 295 companies are currently involved in the hospitality sector, including hotel facilities, Bed&Breakfast and agritourisms. While Figure 5 shows how 3237 available beds are currently distributed in the municipalities. This is a very important sector within the considered UNESCO territory of Figure 1, since large touristic flows are attracted from all over the world every year, making the area also significant from the employment point of view (Regione Piemonte, 2022).

Considering the results of Table 2, obtained for the representative case study, and

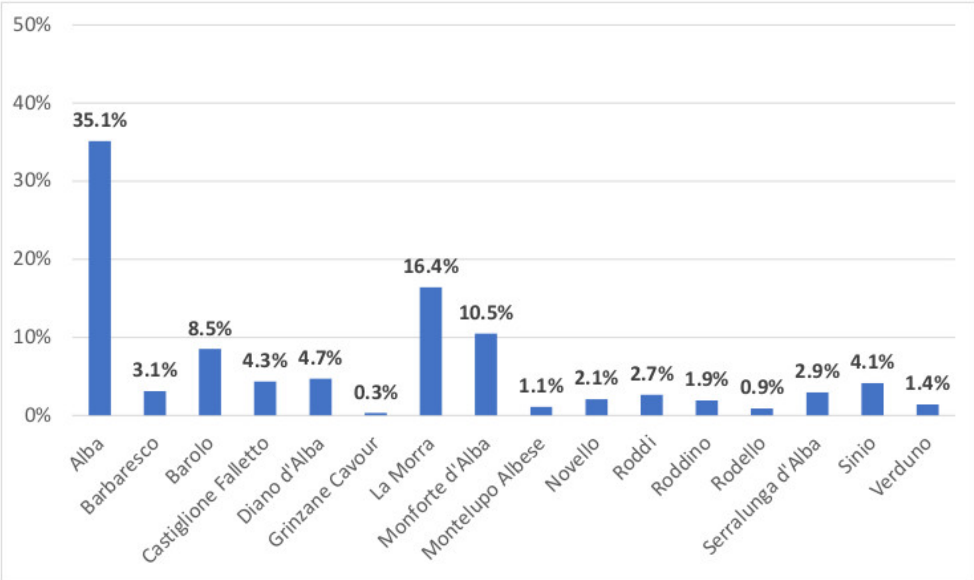

Figure 5. Distribution of the available beds for the hospitality sector by municipalities.

assuming the same results for all the companies in the hospitality sector, the CO_2 emissions were estimated before and after the implementation of the proposed measure according to the number of available beds presented in Figure 5. In this case, the estimated overall reduction of CO_2 emission can be around 25.7% passing from 54.5 $GgCO_2$/year down to 37.4 $GgCO_2$/year. Energy efficiency is hence fundamental to mitigate the environmental impact of the accommodation sector. This sound particularly true in this UNESCO area with a longstanding vocation for tourism where sustainability is nowadays perceived as a fundamental keyword to attract more green emerging tourism (Chen et al., 2022).

Finally, Figure 6 shows how the annual CO2 emissions savings are spread over the different municipalities. Similarly to the winery case, the higher reductions are obtained in the municipalities with the highest number of available beds.

4.3. Residential buildings

Two different possible measures have been proposed to reduce the environmental impact of the residential buildings, as presented in Section 3.3. The measures differ from the technological solutions adopted for the thermal insulation of the opaque envelopes of the building. These solutions present similar results, since both improve the building

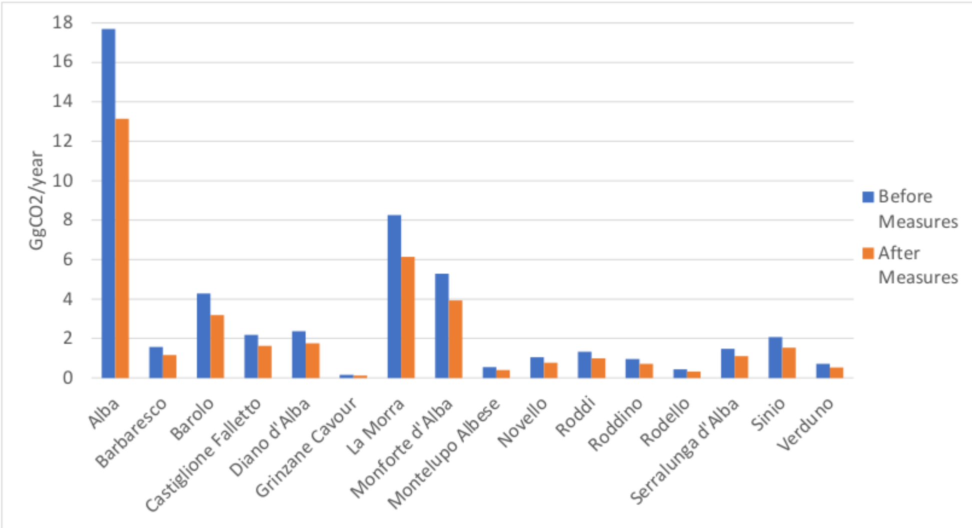

Figure 6. Yearly savings of CO_2 emissions for the hospitality sector by municipalities.

energy efficiency rating of two classes, by reducing the primary energy consumption for space heating. As a consequence, a relevant CO_2 emission reduction is expected in both cases. These results grant the access to the Italian incentive scheme named "SuperBonus" (Governo della Repubblica Italiana, 2020a), where a tax deduction equal to 110% of the capital cost for the energy retrofit of the building can be obtained over 5 years. In this way, the costs for the retrofit are substantially refunded in 5 years, making the measures economically more viable and boosting the residential building renovation market in Italy (Ascione et al., 2021).

Following the bottom-up approach of Section 2, the calculation of CO_2 emission saving on a territorial scale, due to the proposed measures, was firstly based on the identification of the current energy classification of the residential buildings within the 16 municipalities. After, an improvement of the energy efficiency rating of two classes was assumed for all those residential buildings adopting the measures and, consequently, the emission savings were calculated.

Indeed, the energy classification of a residential building is based on the comparison of its energy performance index EPI with the energy performance index of a reference building EPI_{ref} (European Parliament, 2018). This reference building is a building whit the same geometric characteristics, but with higher energy performances (i.e., in line with requirements of the EU Directive). Thus, both EPI and EPI_{ref} should be estimated for all the buildings being studied, if a correct energy classification of them must be achieved.

This evaluations can be performed through the use of datasets currently available, as shown in the workflow of Figure 7 and in line with other similar studies (Afaifia et al., 2021; Yang et al., 2020). In particular, the following datasets were considered:

- the regional dataset (SIPEE) containing the Energy Performance Certificates (EPC) of the buildings (Regione Piemonte, 2020d);
- the regional dataset (BDTRE) containing the buildings plan areas and other main characteristics of the buildings (e.g. designated use of the building) (Regione Piemonte, 2020a);
- the Digital Surface Model (DSM) and the Digital Terrain Model (DTM) of the Piedmont Region (Regione Piemonte, 2020b,c).

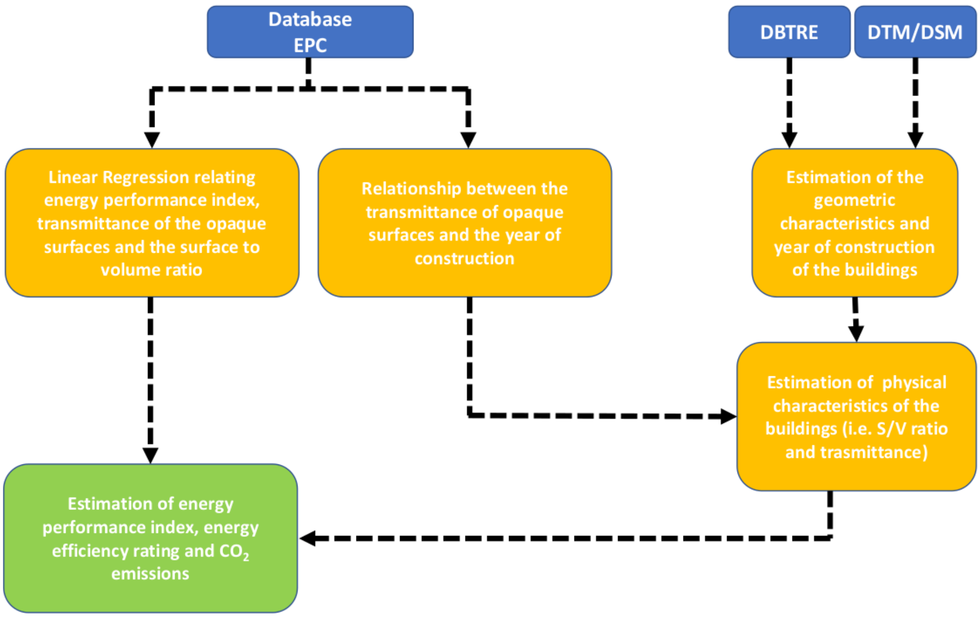

Figure 7. Approach considered to identify CO_2 emissions for residential building.

The first dataset (SIPEE) was considered for identifying a linear regression relating the energy performance index EPI and two main physical characteristics of a building: the average transmittance of the opaque surfaces and the surface to volume ratio. In this way, considering the dataset with Energy Performance Certificates (EPCs), the energy performance index can be estimated for a given i-th building, as follows:

$$\hat{EPI}_i = a_0 + a_1 T_i + a_2 (S/V)_i \tag{1}$$

where $\hat{EPI}_i$, T_i and $(S/V)_i$ are the estimated energy performance index, the average transmittance of the opaque surfaces and the surface to volume ratio for a building, respectively. Similarly, a second linear regression has been identified to estimate the energy performance index of the reference building EPI_{ref}, as follows:

$$\hat{EPI}_{ref,i} = b_0 + b_1 (S/V)_i \tag{2}$$

However, both T_i and $(S/V)_i$ data are not available for all the buildings within the area being studied and in particular for all those buildings without an EPC (i.e. the ones not yet included on SIPEE dataset). Hence, these data need to be estimated as well. In particular, the BDTRE, DTM and DSM dataset was used to calculate the S/V ratio as well as the year of construction of each building, according to the approach proposed in (Vicentini and Mutani, 2012) based on a GIS analysis. The transmittance T was instead estimated through a clustering and classification approach by using the SIPEE dataset. Firstly, all the buildings within the SIPEE dataset were grouped in 9 clusters according to the year of construction reported in Table 11. Then, for each cluster, an average transmittance T was calculated (see Figure 8)

Finally, any building not yet included in the SIPEE was classified according to its year of construction and a corresponding average transmittance T was assumed.

Once the thermal transmittance and the surface to volume ratio was estimated for all the buildings, the linear regressions of Equations 1 and 2 was used to estimate the corresponding EPI and EPI_{ref}. As a consequence, the energy efficiency rating for each building was calculated according to the National guidelines in (Ministry of Enterprises and Made in Italy, 2005), which basically compare the two estimated parameters.

Figure 9 and Figure 10 show the distribution of the energy performance index and

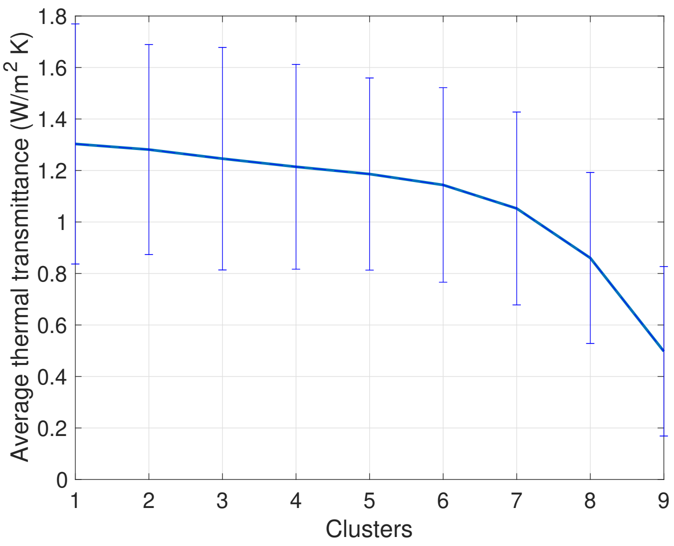

Figure 8. Average thermal transmittance of the opaque surfaces calculated for residential buildings by clusters.

Table 11. Clusters of residential buildings by year of construction

Cluster	Year
1	up to 1900
2	1901-1919
3	1920-1945
4	1946-1960
5	1961-1970
6	1971-1980
7	1981-1990
8	1991-2005
9	after 2005

the energy efficiency rating estimated for the residential building within the 16 municipalities, respectively. It can be noticed that almost all the buildings are affected by scarce thermal insulation corresponding to a higher energy demand and energy efficiency classes with an average energy performance index of around 307 kWh/m^2/year.

The corresponding CO_2 emissions for the residential buildings was then calculated by considering a weighted emission factor of different fuels supplying the buildings (including district heating) multiplied by the $\hat{EPI}$ and the heated floor area (calculated by the BDTRE dataset).

Finally, the emission savings of the residential buildings within the 16 municipalities were identified assuming an improvement of the energy efficiency rating of two classes and thus a reduction in the estimated EPI for the residential building adopting the

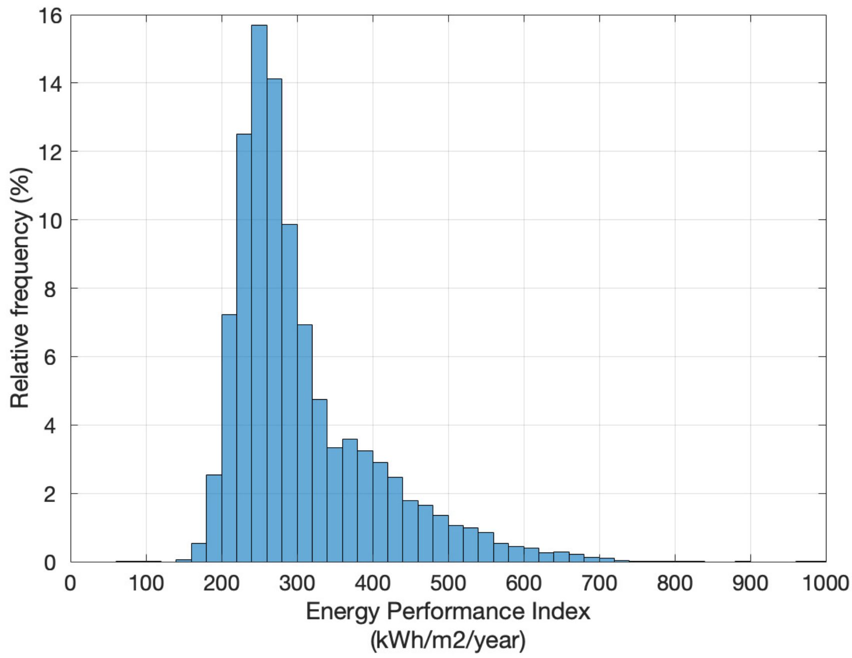

Figure 9. Distribution of Energy Performance index estimated for residential buildings.

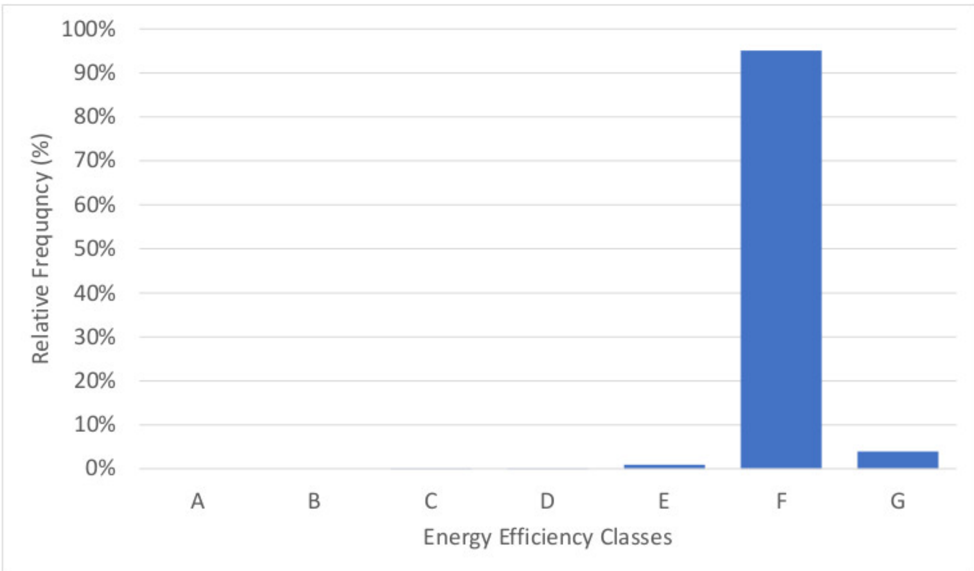

Figure 10. Distribution of Energy Efficiency classes estimated for residential buildings.

measures. In particular, three different scenarios were considered according to different potential diffusion rates of the proposed measures:

- *Moderate scenario*: 10% of the residential buildings will have an improvement of two classes of the energy efficiency rating;

- *Accelerated scenario*: 50% of the residential buildings will have an improvement of two classes of the energy efficiency rating;
- *Fastest scenario*: 100% of the residential buildings will have an improvement of two classes of the energy efficiency rating.

Figure 11 shows the potential reduction of CO_2 emissions estimated for the different scenarios in each municipality. Clearly, the scenario with higher diffusion of the proposed measures ensures an overall reduction close to 37.6% passing from 480.8 $GgCO_2$/year to around 300 $GgCO_2$/year. Lower savings are instead expected for the Accelerated and the Moderate scenarios with an overall reduction of 11.5% and 3.9%, respectively.

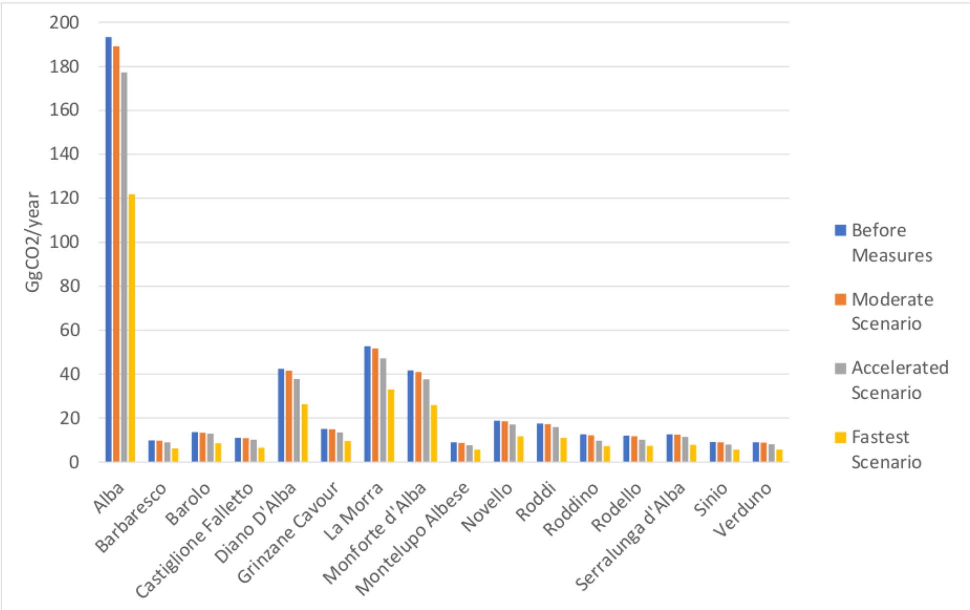

Figure 11. Yearly saving of CO_2 emissions for residential buildings by municipalities.

4.4. Local SME in the food chain

As highlighted in Section 3.4, a potential CO_2 emission reduction of about 30% was estimated for the local SME case study. The proposed measures promote, in fact, a reduction of CO_2 emissions passing from the current 1460 tCO_2/year to 1028.5 tCO_2/year.

As for the wine and hospitality sectors, an approach was identified to spread the result obtained for the single case study across the 16 municipalities within the UNESCO area. In this case, the approach is based on pointing out both the numbers of the current SME in the food and beverage sector deployed within the area and the corresponding current energy demand. Then, the emission reduction estimated for the pilot case is assumed also for all the SMEs individuated within the area.

The energy demanded by the SME has been estimated through an approach similar to the one proposed for the residential building. In particular, the regional EPC database (Regione Piemonte, 2020d) was considered to extrapolate the energy demand of industrial buildings in the food sector, as presented in Figure 7. Figure 12 shows the distribution of the energy performance index estimated for these industrial buildings within the 16 municipalities where an average value of around 361 kWh/m^2/year is expected.

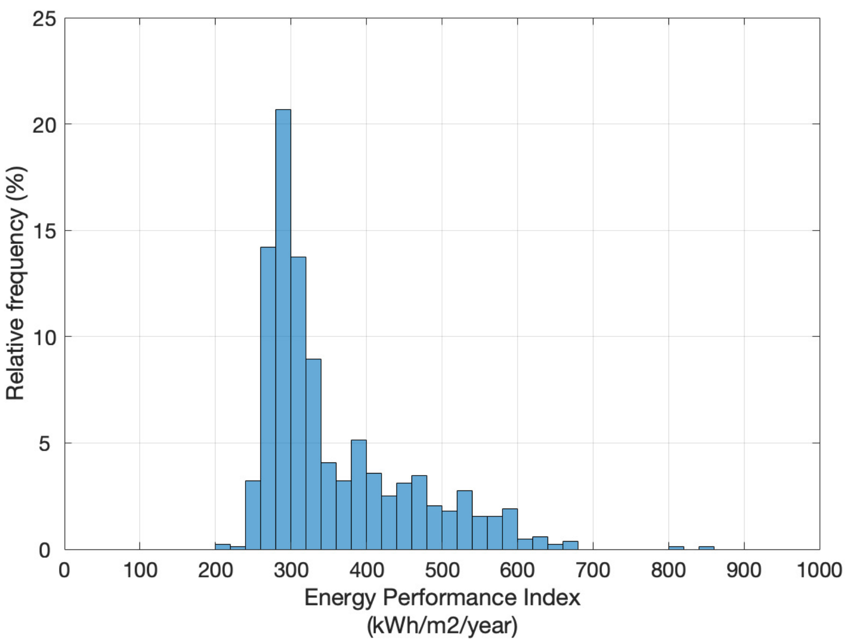

Figure 12. Distribution of Energy Performance index estimated for SME in the food sector.

Considering the estimated primary energy demand of the industrial building and the corresponding CO_2 emission, the estimated emission saving of around 30% was assumed for all the industrial buildings. Hence, Figure 13 reports the emission savings achievable by the local SMEs in each municipality, passing from the current 60.8 $GgCO_2$/year to 42.7 $GgCO_2$/year.

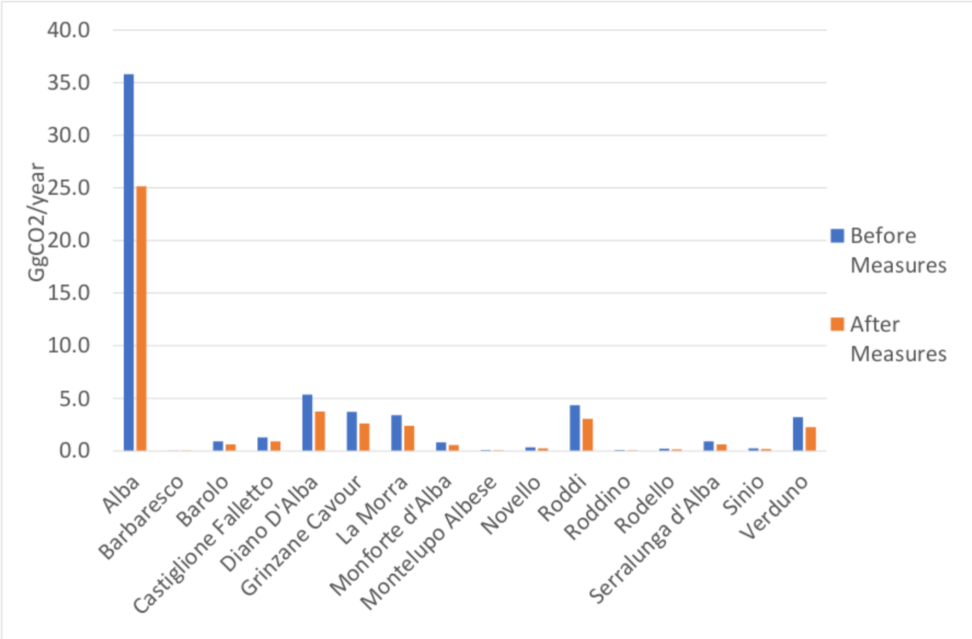

Figure 13. Yearly savings of CO_2 emissions for SMEs by municipalities.

4.5. Private Transport

EVs are the choice for the future decarbonization of the private transport sector, as already highlighted in Section 3.5. In fact, the per unit emission factor of battery electric vehicles (see BEVs in Table 8) is approximately reduced by half compared to the ones of conventional vehicles fuelled by gasoline or diesel. Furthermore, BEVs also eliminate direct emissions (i.e. emissions during travel), while maintaining those due to the consumption of electricity (taken from the grid) needed to charge the EV batteries.

Starting from these considerations, some possible scenarios for the development and diffusion of BEV were assumed with the aim of estimating the potential reduction of CO2 emissions within the 16 municipalities within the UNESCO area. Specifically, the scenarios considered here refer to the ones reported in (Energy and Strategy Group, 2020) assuming two possible future perspectives:

- *Moderate Scenario*: where an EV penetration of 14% is assumed within the circulating fleet by 2040;
- *Accelerated Scenario*: where an EV penetration of 20% is assumed within the

circulating fleet by 2040;

In addition, a different diffusion of BEVs and plug-in hybrid electric vehicles (PHEVs) was then assumed for both scenarios, as indicated in Table 12.

Table 12. EV penetrations assumed for the different scenarios (Energy and Strategy Group, 2020).

	EV Diffusion	
	Moderate Scenario	Accelerated Scenario
BEV	10.5%	15.0%
PHEV	3.5%	5.0%

Considering the current distribution of the circulating fleet presented in Table 7, an estimation of the CO_2 emission by 2040 was performed assuming that the current 36660 passenger cars in the 16 municipalities within the UNESCO area (ACI, 2019) will be replaced by EVs, according to the presumed diffusion indicated in Table 12. Thus, the passenger cars to be replaced by EVs represent a fraction of the current circulating fleet. In particular, the proportion assumed is the same regardless of the fuel supplying the vehicle. In addition, the per unit emission factor assumed for PHEV is equal to the one of the hybrid vehicles presented in Table 8.

Figure 14 reports the annual emissions obtained in the Moderate and Accelerated scenarios. It can be noticed that the diffusion of EVs could reduce the overall CO_2 emissions from 67.6 $GgCO_2$ to approximately 63.1$GgCO_2$ and to around 61.2$GgCO_2$ for the two scenarios, respectively. As a consequence, a relative reduction of 6.7% and 9.5% was estimated for the Moderate and Accelerated Scenario, respectively.

Of course, a more accurate evaluation could be possible if projected and future value of emission factors of Table 8 was used to estimate GHG emissions. For instance, considering a future increase in the renewable electricity production, emission factors for BEV will be lower, as well as a higher efficiency in the internal combustion engines will reduce emission factors for conventional cars in 2040. However, projected emission factors are difficult to be estimated and, for this reason, they are assumed to be equal to the current one. Clearly, this lead to less accurate results, but estimated emission savings can be considered more conservative.

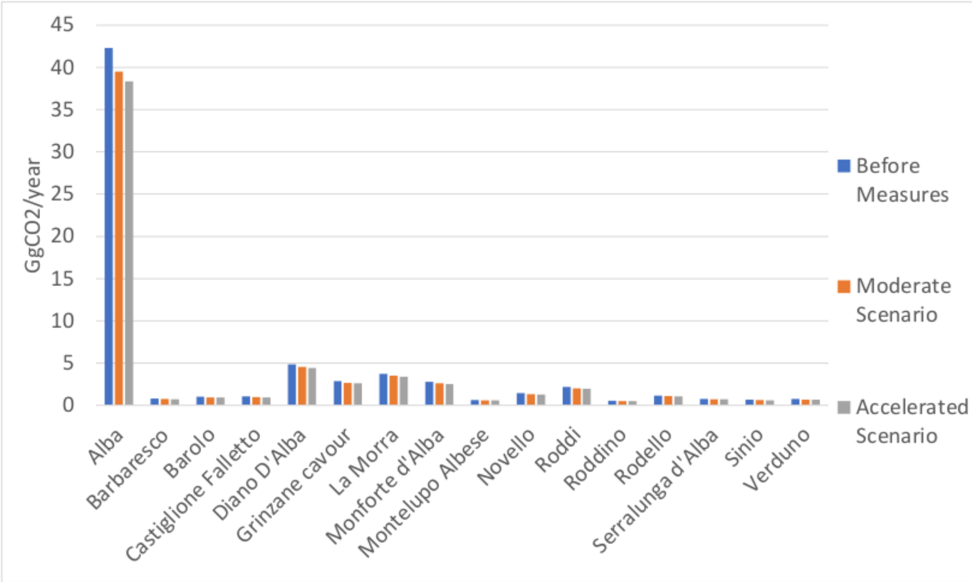

Figure 14. Yearly savings of CO_2 emissions for private transport by municipalities.

4.6. Aggregated results

The aggregation of the results obtained for the different sectors is discussed in this Section to highlight the overall framework of the CO_2 emissions in the studied UNESCO site. The baseline scenario of Figure 15 shows how each private sector can currently contribute to the overall emissions of the UNESCO area (see Figure 1) before the potential implementation of the proposed measures at the territorial level. In particular, Figure 15 highlights how residential buildings have a significant impact, while a lower, but still relevant, contribution appears for the other sectors. This result is of course influenced by the territorial diffusion and distribution of the considered private sectors within the studied area. Nevertheless, the Wine industry has a marginal impact, since the adopted simplified bottom-up methodology does not take into account also the energy consumption for the operation of agricultural machinery and for the winemaking process, but it is more focused on the energy consumption occurring within the buildings used for wine storage where decarbonization actions can be more easily implemented.

Starting from this baseline scenario, the spread of the decarbonization measures identified in Section 3 can lead to a reduction in CO_2 emissions across the whole UNESCO area. However, several different scenarios were identified for some of the

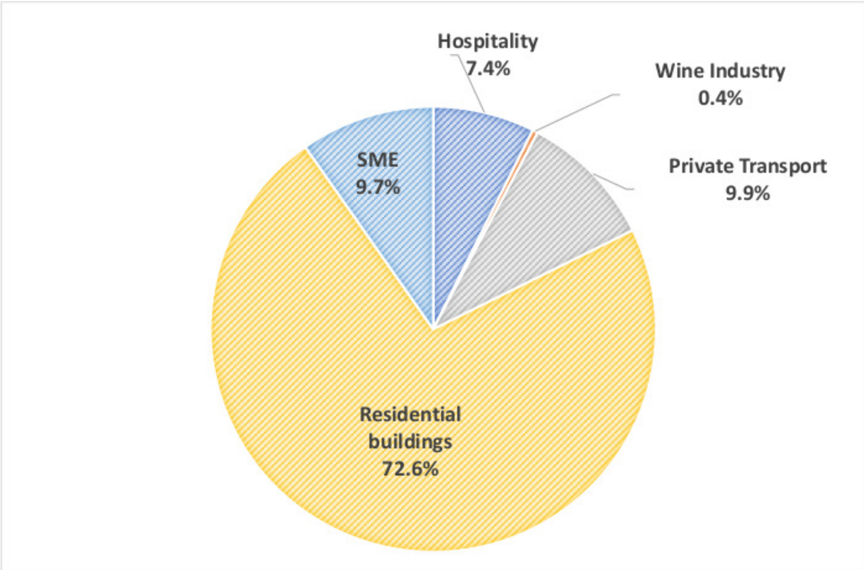

Figure 15. Contribution of the different sectors to the yearly estimated baseline CO_2 emissions.

private sectors (e.g., the transport sector), so the aggregated results can be presented considering two main scenarios capable to highlight the potential range of CO_2 savings:

- A *worst-case* scenario is calculated by summing up the CO_2 emissions savings of the wine industry and the hospitality sector with savings achievable by a moderate diffusion of EVs and a moderate diffusion of energy retrofit in residential buildings. Thus, this scenario represents the minimum achievable reduction of CO_2 emissions and, in practice, the more realistic one since both electrification of transport and energy retrofit of buildings have an expected low diffusion rate (Bianco and Marmori, 2022; Fluchs, 2020) in the near future;
- A *best-case* scenario is calculated by aggregating the CO_2 emission reductions in the wine industry and hospitality sector with savings obtainable by the scenario of accelerated diffusion of EVs and a full diffusion of energy retrofit in residential buildings. Consequently, this scenario represents the maximum possible reduction of CO_2 emissions and, hence, the optimistic one;

Since these two scenarios identify how the reduction of CO_2 emissions can range from a realistic to an optimistic scenario, Figure 16 shows how the carbon emission can change in each municipality following different diffusion pathways of the decarbonization actions. Of course, a greater emission reduction is expected in a more optimistic scenario, so local public authorities should be actively involved to promote this trend.

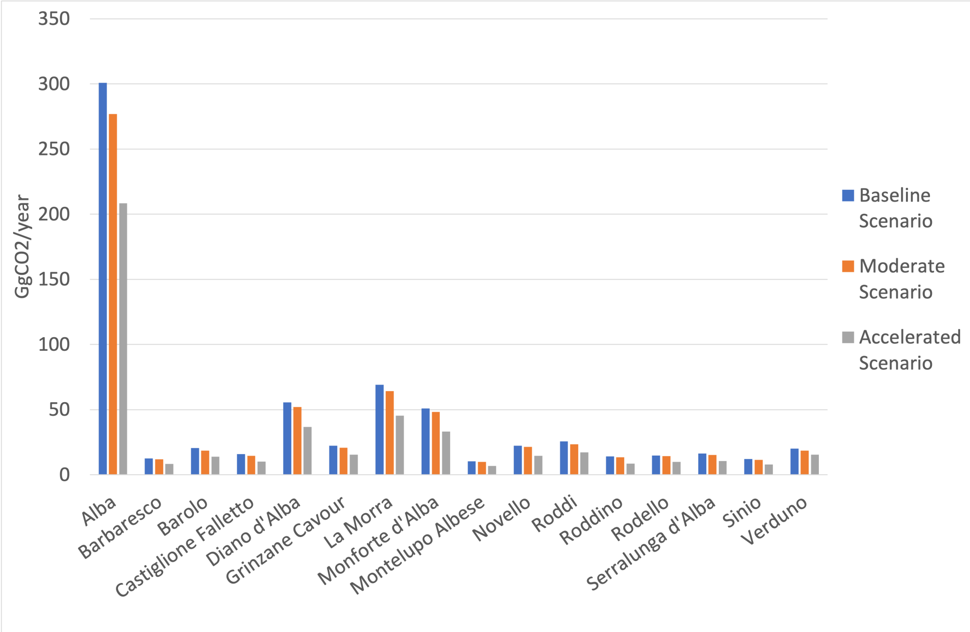

Figure 16. Estimation of the aggregated CO_2 emissions for the worst-case and best-case scenarios.

Additionally, the relative variation calculated for each municipality within the UNESCO area is presented in Figure 17. The minimum ranges between 4% and 9%, while the maximum is between 23% and 40%. Clearly, differences at municipal level can depend on various factors such as the number of available beds in the hospitality sector, the wine production, the number of passenger cars registered, the number of residential buildings, etc.

The estimated yearly emissions of around 683.1 $GgCO_2$ can be thus potentially reduced to 634.4 $GgCO_2$ and 461.7 $GgCO_2$ considering the worst and the best-case scenarios, respectively. These results, as summarised in Table 13, are clearly promising since carbon emissions could be potentially reduced up to 32% on average. This means that the integration of all the proposed measures in Table 10 could positively impact the decarbonization process of the UNESCO area. In particular, all of them are also economically sustainable promoting their diffusion and replicability. However, as already pointed out, some of the proposed measures are typically expensive, but also more effective, like the energy retrofit in residential buildings and the electrification of the private transport. Thus, the current national regulatory framework is still essential

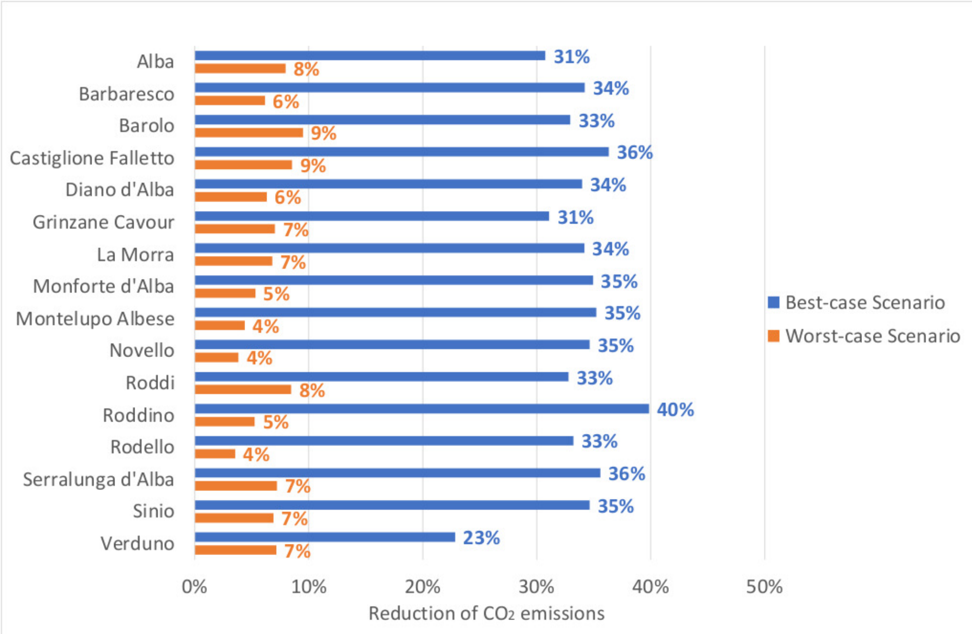

Figure 17. Relative CO_2 emissions savings for the worst-case and best-case scenarios.

to economically support, through incentives, the diffusion and the replicability of the identified decarbonization actions.

Table 13. CO_2 emission savings for the worst and best-case scenario.

		Scenario	
	Baseline	Worst-case	Best-case
Emissions ($GgCO_2$/y)	683.1	634.4	461.7
Savings (%)	-	7.1	32.4

Figure 18 and Figure 19 show the CO_2 emissions estimated at the territorial scale after the potential implementation of all the proposed measures for the decarbonization of the different private sectors considered in this study. As already observed, these Figures point out the range (i.e. the minimum and the maximum level) of the achievable CO_2 emissions considering different diffusion of the decarbonization actions. It is noticeable that the municipality of Alba has the highest emission levels in both scenarios, and consequently also the highest emission reduction. This is due to the higher population and the greater presence of residential buildings, passenger cars, SMEs, etc. compared to the other municipalities in the area. In this view, the municipality of Alba, which is also the cultural and economic center of the area, should be the driving entity for the diffusion of deep decarbonization by promoting all those initiatives exploiting carbon emission reduction and mitigation, following the example of the Province of Siena towards the carbon neutrality (Alleanza Territoriale Carbon Neutrality Siena, 2020). For instance, the creation of a platform for the involvement of all the stakeholders could be a valuable option to support them and inform citizens, SMEs and other actors in the deployment of virtuous behavior and best practices.

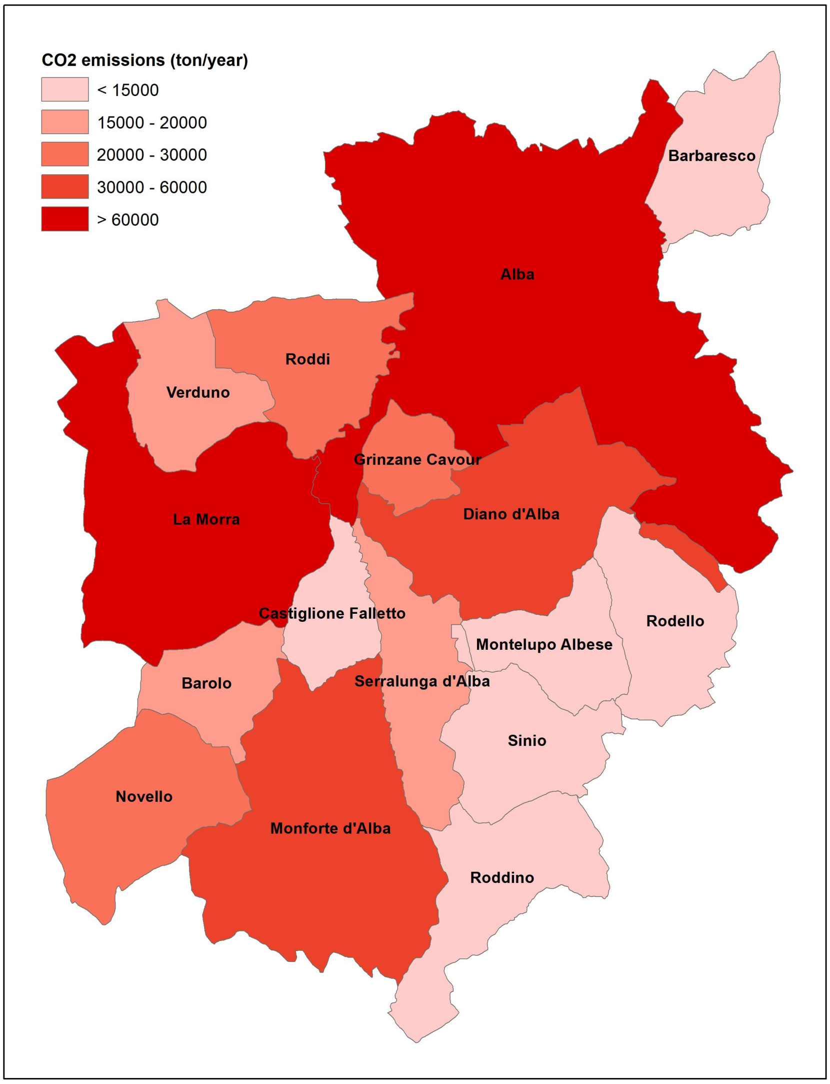

Figure 18. Yearly CO_2 emissions for the worst-case aggregated scenarios.

Finally, Table 14 shows the carbon saving costs or, in other words, the per unit emission saving achievable for each per unit capital costs spent, considering 15 years as average technical lifetime of the implemented measures. Particularly, Table 14 reports carbon saving costs considering the available fiscal incentives. It can be noticed that

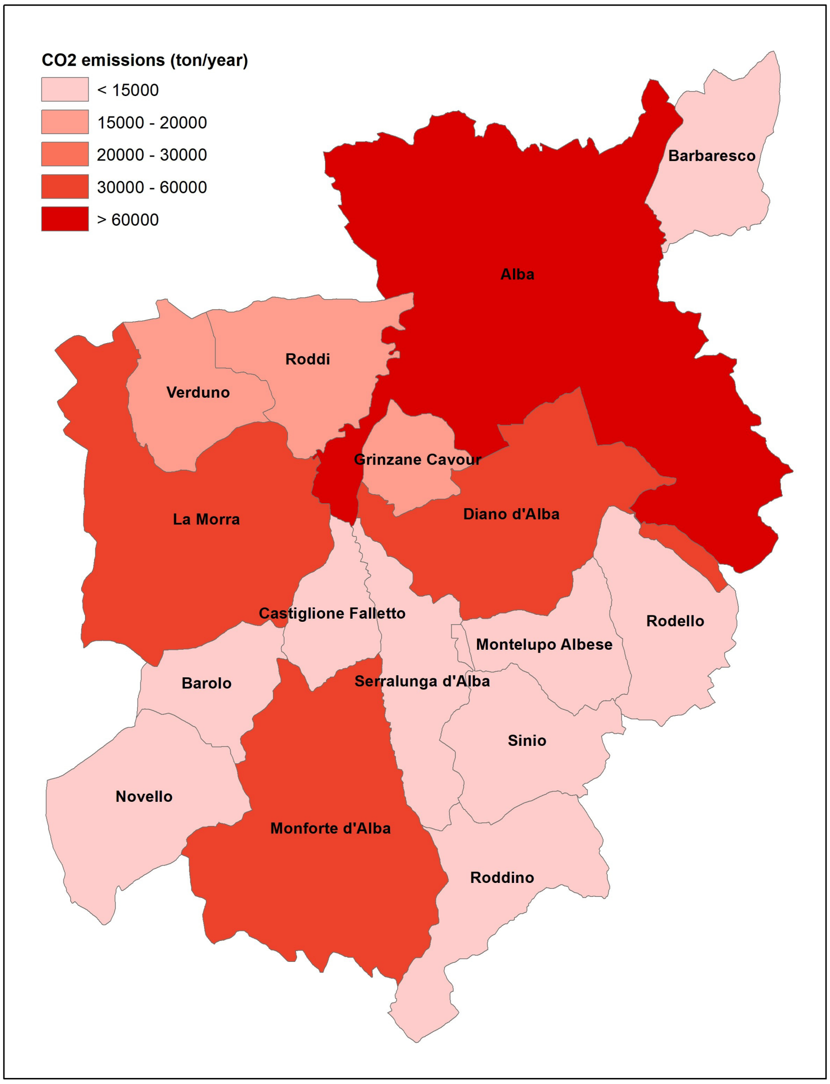

Figure 19. Yearly CO_2 emissions for the best-case aggregated scenarios.

energy efficiency measures for both electrification of private transport and the energy retrofitting of residential buildings are costly compared to the other use cases. This is due to higher investment cost for these actions, even if emission reduction can be significant as in the residential sector. In particular, the higher cost of BEVs has a worsening effect. Thus, further incentives should be adopted in this case to increase the diffusion of electromobility, while residential buildings, as depicted in Section 3.3, could already benefit of fiscal incentives whose effect actually contributes to zero installation costs and zero carbon saving costs.

Lower carbon saving costs are differently expected for the other sectors. In these

Table 14. Per unit investment cost for reducing one ton of CO_2 considering technical lifetime of 15 years.

Carbon saving costs (€/tCO_2)				
Winery	Accommodation Facility	Residential Buildings*	Local SME	Private Transport
193	47	668	59	1676

*This average result is obtained without National fiscal incentive.

cases, the current incentive schemes significantly affect the investment as, for instance, in the installation of PV systems adopted for the accommodation facilities and local SME in the food sector. Hence, these carbon saving appears capable to potentially compensate the external costs of CO_2 emissions, which are presently estimated in a range from 100 to 269 €/tCO_2 (Directorate-General for Mobility and Transport, 2019), making the cost-benefit analysis also positive from a social perspective. Nevertheless, emission savings in residential building and private transport have an impact also on public health due to reduction of local pollutants whose emissions are typically in most populated areas. Thus, further positive externalities should be also expected in these cases.

5. Conclusion

Climate change effects are being more tangible in recent years. Thus, EU political and regulatory frameworks are pushing up the need for substantial and significant reduction of greenhouse gas emissions in all the main economic sectors. In particular, wider diffusion of practical measures within the private sectors can lead to relevant environmental benefits for mitigating climate change effects. This is particularly true within UNESCO sites, where environmental protection is one of the key points. For these reasons, a simplified bottom-up approach has been developed and presented to highlight the potential environmental benefits achievable by spreading a set of proposed energy efficiency measures in different economic sectors across the UNESCO area of Vineyard Landscape of Piedmont.

Firstly, some representative case studies were identified in the UNESCO site according to the specific characteristics of the area being studied. Thus, a winery, an accommodation facility, a residential building, a local SME in the food chain and private transport were considered. After the identification of the current energy demand and carbon emissions, different actions for reducing energy consumption and CO_2 emissions in the pilot cases were evaluated also from the economic point of view, since economic feasibility is also fundamental for the diffusion of the adoptable measures. These include the implementation of RES-based energy production systems, like PV and biomass boilers, as well as energy efficiency measures to reduce primary energy consumption like the installation of CHP units, the improvement of thermal insulation in residential buildings, the migration of private mobility from conventional internal combustion engines to electric vehicles.

The estimated environmental benefits for the case studies were then spread across the UNESCO site, evaluating their diffusion by means of the available regional and local databases. Since different diffusion rate for the proposed measures is expected in some case studies, two scenarios have been considered: a more realistic diffusion pathway (i.e. worst-case scenario) and an optimistic one (i.e., the best-case scenario). In this way, a possible range of CO_2 emissions reduction was estimated at a territorial scale. Considering a current estimated yearly emission of around 683.1 $GgCO_2$, the proposed measures could be capable to reduce environmental impacts by 7.1% and 32.4% in the worst-case and in the best-case scenario, respectively. Clearly, some of the proposed measures have a more significant impact than others, due to the current territorial diffusion of the case studies and their energy demand. In this view, higher priority should be given to the energy retrofit of residential buildings as well as to the electrification of passenger cars. Nevertheless, these measures are typically costly and, hence, the current national supporting scheme is still fundamental to promote the exploitation of these solutions. In particular, more support should be given to the electrification of private transport suffering of higher BEV investment cost.

Additionally, the local public authorities should play a key role in promoting these measures for exploiting carbon emission reduction through the creation of a platform for the share of best practices and the engagement of all the active stakeholders in the area.

Further relevant environmental benefits could be potentially exploited in all those case studies where natural gas is used, since bio-methane can represent a valuable option. However, the current Italian regulatory framework still does not admit the adoption of this renewable source for energy purposes, so future environmental improvements are expected in the next future to prevent climate change.

Finally, according to the availability of the local, regional and national database, the simplified bottom-up approach presented here could be potentially adopted both in other contexts and UNESCO sites to identify more specific energy-efficiency measures for limiting greenhouse gas emissions and improving environmental benefits.

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