Exploring potential synergies among energy sectors in alpine regions: the case of Valle d'Aosta

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Abstract:

Renewable energy sources could play a key role in curbing carbon dioxide emissions worldwide, provided their successful integration in the electricity generation sector. With this respect, a Smart Energy System approach allows to accommodate ever-larger shares of renewables benefiting from a synergic interaction among the different energy sectors, with a view to shifting final consumption from fossil fuels to electricity. In this perspective, opportunities for a carbon-free sustainable future are investigated in this work for an Italian alpine region, Valle d'Aosta, characterised by an abundance of hydroelectric power that currently exceeds electricity demand. Future energy scenarios are simulated with the help of EnergyPLAN software assuming the electrification of both transportation and heating sectors, which are currently heavily relying on oil-based fuels. Moreover, considering buildings heat demand, some areas of the region are not reached by the natural gas network. Proper energy efficiency measures are evaluated along with the possibility of optimizing the use of other renewable resources, such as local wood biomass for space heating and solar thermal for domestic hot water production. Results show that the enhanced management and usage of renewable power can lead to a significant reduction of CO_2 emissions and helps pave the way for an optimal use of local available renewable energy sources for Valle d'Aosta Region, thanks to an increase in electricity penetration. At the same time, the benefits of electricity usage vary for different sectors, due to the specific features of the energy demand (e.g. industries, remote areas). Electricity penetration should therefore be tailored to the proper final uses, to fully exploit local resources and promote the sustainability of the entire energy system.

Keywords:

Large-scale RES, Hydroelectric power, Electric vehicles, Heat pumps, EnergyPLAN, Smart Energy System, CO_2 emissions reduction.

1. Introduction

Climate change is becoming a key aspect in several national energy policies worldwide, as demonstrated by the binding targets set among almost 200 countries in the Paris Agreement. Furthermore, European Union defined the 2030 Energy and Climate Package [1], as an update of the previous targets set for 2020, in which member states agreed on achieving important goals such as reducing CO_2 emissions, improving the share of renewable energy sources (RES) and enhancing energy efficiency policies.

RES potential shows a large variability across Europe, with higher solar productivity in Southern countries, whereas wind potential is mainly present in northern regions. More complex distributions can be observed for other sources, including biomass, hydro or geothermal. In particular, considering the Alpine Region, there is currently a widely deployed network of hydro power plant of different sizes, as a result of the historical development of this source. In some cases, the large amount of hydroelectric power generation exceeds the demand and is exported to neighbouring Countries, states or regions. On the other hand, since some rural areas are not reached by natural gas grid, the use of oil derivatives for heating is still very diffused. Furthermore, some territories are characterized by the presence of large tourists flows, resulting in the need of oversized infrastructures to cope with massive variability of energy demand (with weekly and seasonal trends). In addition, due to the central location of the Alpine Region in Europe, mobility planning needs to cope with road and rail freight traffic flows on the North-South axis.

Due to these peculiar challenges, specific local energy policies need to be implemented by matching the regional characteristics of the mountain areas with the existing national policies. Transnational and multilevel collaboration is crucial to support effective energy planning in such regions [2]. The availability of excess local power generation from RES can be exploited by increasing electricity penetration in final uses, mainly in transport and buildings heating [3]. Multiple studies have evaluated the potential electrification of the heating sector, by considering the introduction of heat pumps (HP) to exploit electricity produced by renewable energy [4, 5] and explaining the benefits of Power-to-Heat [6]. Other studies focus on the use of renewable electricity in the transport sector [7, 8], which is gaining interest to decrease the dependency on oil and at the same time provide more flexibility to the power network thanks to a significant deployment of electric vehicles (EV) in place of conventional cars [9]. These approaches are very important for paving the way to 100% renewable Smart Energy Systems [10, 11], since they can lead to the integration of different sectors and allow to exploit every synergies between them.

Usually the main obstacles to the spread of these approaches is the still low share of RES [12], and the lack of political signals to support low-carbon transition [13]. On the other hand, local pilot projects may trigger policy choices and a wider adoption of RES technologies. In literature there are examples of low carbon strategies that are studied in different European countries: Lund et al. [14] show an analysis of 100% renewable energy system for Denmark by 2050, while Connolly et al. [15] present a similar study for Ireland. Both research works are performed by using the software EnergyPlan, which allows taking into account all the sectors of an energy system in order to consider the optimal integration among them. EnergyPlan has been used for designing optimized energy scenarios for an Italian Alpine Valley in Trentino [16], and it could be used for local energy modelling and planning in other similar regions.

The contribution of this paper is to analyse the case of Valle d'Aosta, a North-Western Italian region, evaluating future scenarios of electricity penetration in the Heating and Transport sectors. Valle d'Aosta is affected by a situation common to the Alpine Region: power sector is characterized by an abundance of electricity production from hydroelectric power plants, that is almost four times the demand [17]. Heating sector is strongly dependent on fossil fuels, due to the fact that some areas of the region are not reached by the natural gas grid. The same dependence on fossil fuels interests the Transport Sector, as a result of few spread of electric vehicle infrastructure (charge station, etc.). Nowadays the excess electricity of Valle d'Aosta is exported to the neighbour regions but, in the perspective of exploiting local resources, a portion could be used in order to substitute fossil fuels in sectors such as heating and transport, which are currently heavily relying on oil-based fuels.

2. Methodology

Valle d'Aosta energy system has been modelled with the support of EnergyPLAN tool [18]. The software simulates the operation of any energy system taking into account electricity, heating, cooling, industry and transport sectors and evaluates their possible interactions according to a Smart Energy System perspective. A variety of scenarios can be created by changing relevant input pertaining to a particular sector and compared with respect to energy and/or economical indicators. Performing simulations on an hourly basis, EnergyPLAN also requires power distributions to be implemented, defined as the ratio between power demand (or generation) at a particular hour and its yearly peak value.

A reference model for Valle d'Aosta energy system has been defined with reference to the year 2015 and characterised in terms of demand and supply in line with the latest available data, derived from official regional energy balances [17]. Future scenarios have been defined and analysed implementing sustainable measures in the regional energy system tackling the threat of fossil fuels usage in both heating and transportation sectors.

2.1. Historical scenario

2.1.1. Demand

According to the Regional Ministry of production Activities, Energy, Labour and Environmental policies of Valle d'Aosta, the gross final energy consumption was 4440.6 GWh/year in 2015. Energy requirements are displayed in Table 1 divided by source among end uses.

Table 1: Valle d'Aosta energy demand (GWh/year) by source among end uses - values for 2015

Sector	Coal	Oil	Natural Gas	RES	Heat	Electricity
Agriculture	-	19.9	-	0.1	-	4.8
Industry	-	145.9	423.7	13.9	-	366.7
Residential and services	0.4	859.2	414.7	473.5	61.9	504.7
Transportation	-	1151.3	0.1	-	-	-
Total final demand	0.4	2176.2	838.5	487.5	61.9	876.2

As for residential and services sector, fossil fuels and biomass consumption have been allocated entirely to space heating purposes; HP electricity consumption is equal to 12.48 GWh/year and they contribute to a heat demand of 30.95 GWh/year with a COP equal to 2.48; no electric boilers have been included. Hourly distributions for individual heating was derived from the analysis conducted by Calise et al. [19], where a robust methodology is implemented specifically for the Italian case based on degree-days and ultimately validated by modelling the national residential building stock, dynamically simulated in TRNSYS. The particular heat load distribution for Valle d'Aosta has been obtained from a weighted average between zones E and F applying a population share of 58% and 42% respectively.
Electricity transmission and distribution losses have also been included and account for 208.40 GWh/year leading to an overall electricity demand of 1,084.60 GWh/year. In the absence of hourly data for this particular region, the national electricity hourly distribution has been used and derived from Terna, the grid operator for electricity transmission in Italy, with reference to 2015 [20].
Table 2 shows fuel consumption in the transport sector divided by fuel.

Table 2: Fuel consumption (GWh/year): transport sector - values for 2015

Fuel	Fossil	Biofuel
JP	7.2	-
Diesel	780.0	40.0
Petrol	304.0	
Natural gas	0.1	
LPG	20.0	

Primary energy losses have been also included in the model expressed as percentage of the total fuel consumed and set to 4.56% for natural gas.

2.1.2. Supply

Thermal and electric energy supply has been modelled with reference to regional energy balances (BER from here onwards) technical report for 2015 [17]. With respect to heat production, the software allows a subdivision into three main groups: individual boilers, district heating boilers (DHP), cogeneration power plants operating respectively in back pressure (CHP2) and condensing mode (CHP3). This latter category includes large CHP extraction plants that can also operate on an electricity-only basis.

With reference to Valle d'Aosta region, all power plants are assumed to belong to CHP2 group. In particular, cogeneration power plants supplying district heating networks are fully described in the annual report provided by the National Association of Urban Heating (AIRU) [21]. Technical features are displayed in Table 3; consumption is further distributed among plants and fuel type in Table 4.

Table 3: Operating parameters and energy consumption: CHP and boilers for DH networks - values for 2015

Parameter	Units	CHP	Aux boilers	DH boilers	Total
Electric capacity	[MW]	9.2	-	-	9.2
Thermal capacity	[MW]	10.6	66.5	26.6	103.7
Electric efficiency	[-]	24.1%	-	-	
Thermal efficiency	[-]	56.9%	91.0%	77.5%	
Fuel consumption	[GWh]	35.7	27.7	50.2	113.6
Electricity generated	[GWh]	8.6	-	-	8.6
Heat generated	[GWh]	20.3	25.2	39.0	84.5

Table 4: Fuel distribution (GWh): CHP and boilers for DH networks - values for 2015

Fuel	Units	CHP	Aux boilers	DH boilers	Total
Biofuels	[GWh]	29.1	-	50.2	79.3
Natural gas	[GWh]	6.6	26.8	-	33.4
Oil	[GWh]	-	0.9	-	0.9

In the absence of additional information, district heating distribution has been taken from Denmark case study from models available at the EU-funded project Heat Roadmap Europe database [22].

An additional electric capacity of 3.2 MW has been included to take into account CHP plants not associated with district heating, thus leading to a total 12.4 MW gross installed capacity and 15.0 GWh electricity generated by thermal plants as reported by Terna for 2015 [20]. Such plants have been included in the dedicated industrial CHP section within the software.

Renewable energies capacities are listed in Table 5 along with the overall annual production, highlighting the lion's share taken by hydroelectric power plants. Being power distribution not available at a regional level, authors made use of national values as provided by Terna on an hourly basis [20].

Table 5: RES installed capacity (MW) and gross generation (GWh) - values for 2015

Source	Capacity	Generation
Hydro	950.7	3465.0
of which river	*125.7*	*803.5*
Onshore Wind	2.6	3.8
Photovoltaic	21.83	24.1

Regional transmission line capacity has been set to zero so as to quantify on an hourly basis the surplus that arises when power generation exceeds gross demand. Such excess of electricity, currently exported, is intended to be exploited within the energy system itself in the context of an integrated and holistic approach.

2.1.3. Model validation

Valle d'Aosta reference scenario for 2015 has been validated taking into account RES and CHP electricity generation (this latter includes production from biomass), TPES (Total Primary Energy Supply) as provided by BER [17]; CO_2 emissions are equal to 754.7 kt for the base case scenario. Also, the model identifies Critical Excess Electricity Production (CEEP) as the production that exceeds the transmission line capacity (net of the electricity exported). Such surplus, which is unavoidable with RES significant penetration, is not allowed in real operation and translates into energy curtailments. Scenarios have been simulated under the conservative assumption that production exceeding the electricity demand cannot be exported (whereas in 2015 electricity net export was 2422.5 GWh). The difference between model results and actual values is acceptable (below 0.2%) as shown in Table 6.

Table 6: Model validation with reference to 2015 data (GWh)

Indicator	Model	Actual	Difference
TPES	7149.2	7135.9	0.2%
Net Export/CEEP	2422.9	2422.5	0.0%
RES electricity	3492.5	3492.5	0.0%
CHP electricity	8.59	8.59	0.0%
CHP heat (to DH)	20.3	20.3	0.0%

2.2. Future scenarios

Possible different future scenarios have been defined, analysed and compared assuming a progressive electrification of both transportation and individual heating sectors. Current carbon-intensive technologies have been replaced by more efficient alternatives assuming a low, medium and high degree of penetration with the aim of progressively shifting consumption from fossil fuels to electricity in a view to exploit the abundance of local renewable power from hydroelectric plants in the region.

In accordance with [23], which has performed a focused research on the future impacts of climate change on hydropower productivity on this very same region, a decrease of 10% of annual hydroelectric generation has been included into the model.

2.2.1. Heating sector

With respect to heating sector, a first assumption has been made concerning individual heating demand, foreseeing a reasonable 10% reduction due to the stricter standard in terms of building energy efficiency for new buildings and renovations. A conservative approach has been chosen, since the interest of the research is the evaluation of the potential impact of different electricity penetration levels on the heating demand of the buildings.

Table 7 reports the assumptions that have been made for the future development of the share of heating demand that will be fulfilled by different technologies. In particular, HP penetration is a key parameter for the definition of the different scenarios in the Heating Sector, being 10%, 30% and 60% the shares associated with Low, Medium and High penetration scenarios respectively. The increase in HP penetration occurs at the expense of diesel oil and natural gas and, in minor share, of district heating. However, it has to be noted that a switch from diesel oil to natural gas with respect to the 2015 consumption has been considered also for the baseline (Low penetration) scenario. Wood biomass has not been substituted by HP, in the perspective of decreasing CO_2 emissions as main policy target. The share of wood biomass has been kept constant, rather than the annual amount of energy, in the assumption that the number of plants will not change (with an eventual evolution of their efficiency) but the annual heat demand will decrease due to better insulation and quality of the buildings. Finally, the increase in DH share with respect to 2015 is related to the current and future implementation of two gas-fired DH systems in Aosta and Cervinia, that will consistently increase the heat demand from DH in the region. A slight decrease of fossil DH has been also considered for Mid and High scenarios. The share of natural gas boilers has been calculated by difference, given the hypotheses described above for the other technologies.

Table 7: Shares of heat demand by technology values for 2015 and future assumptions

Technology	2015	Low	Medium	High
HP	1.8%	10.0%	30.0%	60.0%
Oil boilers	46.4%	15.0%	10.0%	1.0%
Natural gas boilers	23.7%	42.3%	28.2%	8.5%
Wood biomass boilers	24.0%	24.0%	24.0%	24.0%
DH	3.9%	8.6%	7.8%	6.5%

COP value for future scenarios has been estimated with a 25% increase with respect to 2015 and calculated according to the information reported in [17], resulting in an average overall value of 3.01. Such value has been derived from a weighted average of existing HP operating in the region from 2007 to 2014, which are a mix of ground source and air HP.

HP penetration has not been pushed to higher values due both to the interest in keeping the use of wood biomass as a sustainable alternative, and to the limitations set by some holiday houses, for which the low occupancy rate throughout the years would hinder the use of HP due to their higher fixed costs and lower operating temperatures.

2.2.2. Transport sector

The second sector that has been considered in this study for increasing electricity penetration is transport, with particular attention on the light-duty vehicles (LDV). In line with the procedure followed for HP penetration, three different shares of EV have been considered (Low, Medium and High), as described in detail below. In the present study the analysis has been limited to private LDV, which are the most promising sector for electric vehicles; potential of alternative fuels for heavy commercial vehicles have also evaluated as described in the following (section 2.2.3.).

Fuel consumption for transport in the region has seen a decrease of both petrol and diesel in the last decade [17], reaching values of 820 GWh and 304 GWh respectively in 2015. There are around 200,000 vehicles in the region, of which roughly one third is represented by petrol cars, one third by diesel cars and the remainder by other vehicles (trucks, light commercial vehicles, etc.). Since there are no information on the fuel consumption per type of vehicle, some assumptions in terms of subdivision have been performed from the available data. In particular, petrol consumption has been totally allocated to LDV, and a similar share of diesel has been calculated based on the number of diesel-powered LDV. Both an average higher mileage (+20%) and different LDV specific consumption have been considered (57.5 kWh/100km for petrol and 50.0 kWh/100 km for diesel, calculated from [24]), resulting in an estimated diesel consumption for LDV of 340 GWh. A decrease in fuel consumption has been considered when modelling future scenarios resulting in 51.3 kWh/100km and 45.7 kWh/100 km for petrol and diesel LDV respectively [24].

The remaining part, which is the main share of diesel consumption (516 GWh), has been allocated to the other vehicles but chiefly to the significant share of freight transport flow that is affecting the region (which is seeing around 700,000 trucks per year crossing the borders with France and Switzerland [17]). A fuel economy improvement has been also considered for heavy commercial vehicles and translated into a 15% reduction in diesel consumption in future scenarios.

It has to be noted that also for LDV a share of consumption should be allocated to passing traffic (as well as for tourists), but since no information is available it is difficult to evaluate this aspect. On the other hand, for the purpose of this study, the total energy consumption in the region has been considered, both from citizens and tourists (the latter representing a considerable share, with an average of 9,000 presences per day plus the people owning holiday houses [17]).

The assumptions for the future scenarios with respect to EV are summarized in Table 8. Fuel consumption has been estimated by considering a specific consumption for EV of 16.8 kWh/100km for future scenarios (calculated as 15% decrease from current values) assuming a weighted average between battery and plug-in electric vehicles accounting respectively for 70% and 30% and of total EV fleet and taking also into account auxiliary consumption as well as

more realistic real driving conditions [25, 26].
EV shares for Low, Medium and High scenarios have been set to 20%, 50% and 80% respectively. A 100% share has been avoided to take into account the share of consumption from vehicles of tourists, on which local policies have no impact.

Table 8: Energy consumption by type of fuel (GWh) - values for 2015 and future assumptions

	2015	Low	Medium	High
Electric Vehicles	0	44.9	112.4	179.8
Petrol	304.0	445.9	275.6	106.2
Diesel (LDV)	317.1	91.6	61.1	30.5
Diesel (other)	462.9	404.6	404.6	404.6
EV share [-]	0%	20%	50%	80%

2.2.3. Power-to-Gas/Liquid

Power-to-gas/Liquid (P2G/L) technologies represent a promising solution to further exploit RES surplus towards different sectors within the energy system. Synthetic gas and liquid fuels (methanol/DME) can respectively replace natural gas in the grid and diesel consumption in the freight transportation where EV cannot penetrate.
P2G/L have been modelled with reference to a previous work of the authors [27]; Tables 9 and 10 report gasification and hydrogenation operating parameters.

Table 9: Gasification plant operating parameters

Parameter	Value
Steam share	0.13
Steam efficiency	1.25
Cold gas efficiency	0.90

Table 10: Hydrogenation methods operating parameters

Method	Efficiency		Hydrogen share	
	SNG	P2L	SNG	P2L
Biogas hydrogenation	0.83	-	0.50	-
Syngas hydrogenation	0.87	0.60	0.36	0.38

Synthetic gas and methanol is assumed to cover 25% of natural gas consumption for individual heating and 25% of diesel consumption for heavy transportation respectively. Table 11 lists P2G/L parameters related to electrolysers capacity, hydrogen storage capacity and biogas and biomass requirements for electrofuels production. Electrolysers capacity has been set to 4 times the average value necessary to produce the annual amount of hydrogen for biogas/biomass hydrogenation processes, hydrogen storage capacity allows to store 6 days hydrogen production at the electrolyser rated power.

Table 11: P2G/L power and energy requirements at different HP penetration levels

Parameter	Units	HP-Low	HP-Medium	HP-High
Electrolysers capacity	MW	99.38	81.69	57.03
Hydrogen storage capacity	GWh	14.31	11.76	8.21
Hydrogen production	GWh/year	209.52	181.16	141.64
Biogas required	GWh/year	50.00	33.30	10.02
Syngas from biogas	GWh/year	83.32	55.49	16.69
Biomass required	GWh/year	328.19	302.80	267.40
Syngas from biomass gasif. ->P2G	GWh/year	83.32	55.49	16.69
Synthetic liquid fuel	GWh/year	102.95	102.95	102.95

3. Results

Sustainable measures have been applied to heating and transport sectors of Valle d'Aosta region in a view to exploit the otherwise-exported renewable surplus from hydro power thus reducing at the same time fossil fuel consumption in such carbon intensive sectors. The variety of possible scenarios previously defined are compared in this section in terms of crucial environmental and energy parameters.

Figure 1 shows CO_2 emissions reduction with progressively increasing HP shares, parameterised with respect to EV penetration in the private vehicle fleet. Reduction rate is higher from base case to mid-HP scenarios due to the significant reduction of oil in the heating sector. EV positively contribute to CO_2 emissions reduction: at a given HP share, CO_2 emissions can be further reduced by approximately 5 and 7 percentage points with EV replacing 20 and 50% of the conventional fleet respectively, by another 7% when EV are further pushed to 80% of circulating fleet. At the highest HP and EV penetration with P2G/L technologies replacing 25% of both natural gas consumption for individual heating and diesel for heavy transport, CO_2 emissions can be reduced by 60% with respect to 2015.

The electrification of heating and transport sectors allows RES surplus to be conveniently used in place of fossil fuels; its reduction, under a progressive degree of electrification, is displayed in Figure 2. Overall, when HP and EV are at their highest level, the excess of renewable power is reduced by 50% with respect to 2015 level and by 56% when P2G/L processes are added in the energy system. It is worth observing that the reduction in CO_2 emissions when P2G/L is included in the analysis occurs at the expenses of a considerable consumption of electricity generation due to the relatively low overall process efficiency. In the particular case of Valle d'Aosta such power requirement comes from hydroelectric energy, however, in different contexts characterised, for instance, by higher shares of non-programmable RES or conventional fossil fuelled plants, an extensive deployment of P2G/L may ultimately lead to a negative impact on sustainability.

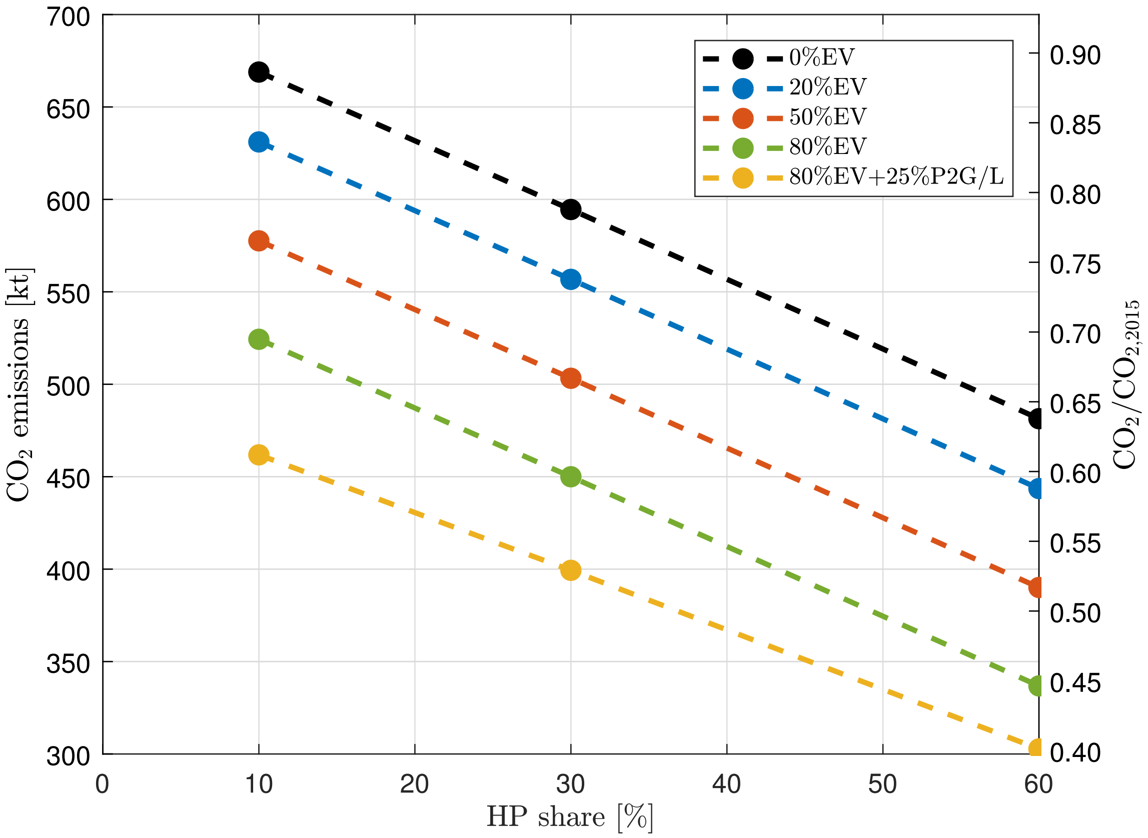

Figure 1: CO_2 emissions variation under progressively increasing HP and EV shares

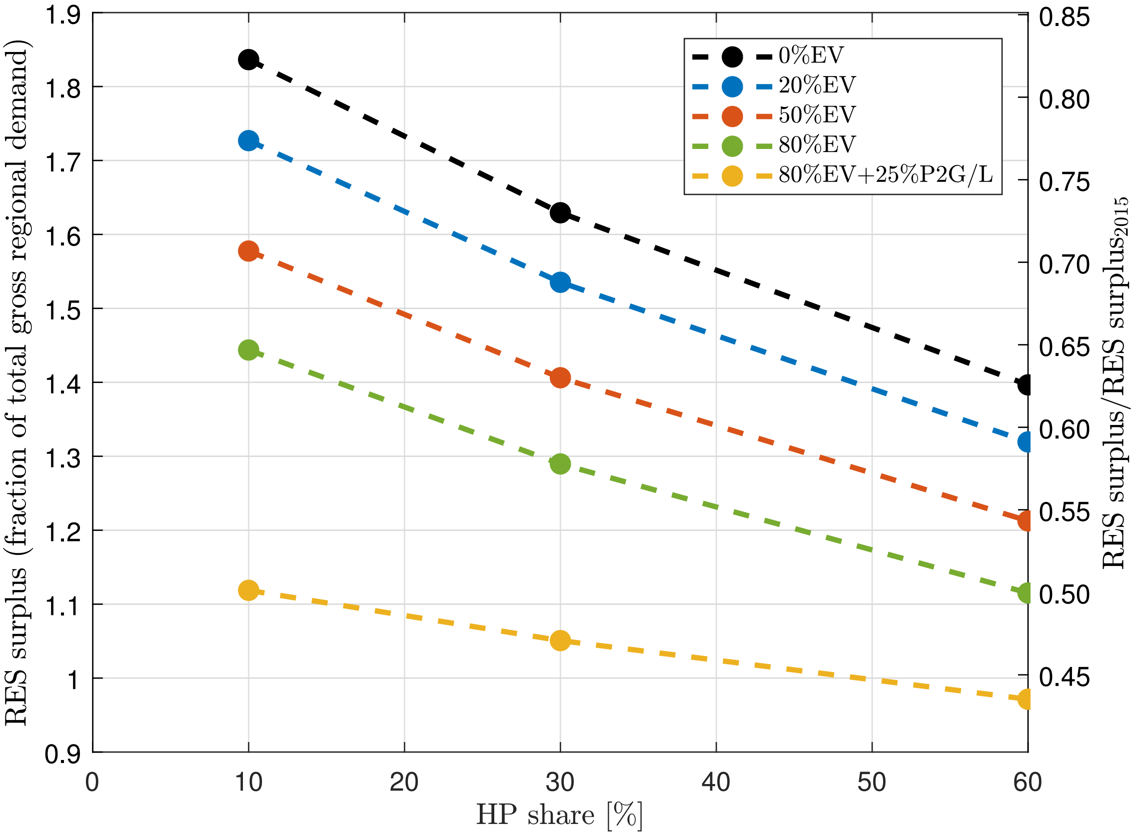

Figure 2: CO_2 emissions variation under progressively increasing HP and EV shares

Moreover, the excess of renewable generation decreases at a lower rate with respect to CO_2 emissions. In fact, as shown in Table 12, the increase in electricity demand, with respect to 2015, when HP penetrate the heating sector is not entirely fulfilled by hydroelectric surplus and part of the overall demand has to be covered by import (up to 16% of the total additional demand at the highest HP and EV penetration). CO_2 emissions related to electricity import are not taken into account in this analysis.

Table 12: Additional electricity supply and demand (GWh) for different scenarios combinations

	HP	EV	RES	CHP	CEEP	Additional Production	Additional Demand	Import
HP-low EV-low	34.0	44.9	69.0	8.4	-411.5	77.5	78.9	1.5
HP-low EV-mid	34.0	112.4	136.4	8.4	-478.9	144.9	146.4	1.5
HP-low EV-high	34.0	179.8	203.8	8.4	-546.3	212.3	213.8	1.5
HP-mid EV-low	127.0	44.9	149.2	6.7	-491.6	155.9	171.9	16.0
HP-mid EV-mid	127.0	112.4	216.6	6.7	-559.0	223.3	239.3	16.0
HP-mid EV-high	127.0	179.8	284.0	6.7	-626.4	290.7	306.8	16.0
HP-high EV-low	266.4	44.9	236.5	4.2	-578.9	240.7	311.3	70.7
HP-high EV-mid	266.4	112.4	303.9	4.2	-646.3	308.1	378.8	70.7
HP-high EV-high	266.4	179.8	371.3	4.2	-713.7	375.5	446.2	70.7

In this regard, electricity and thermal storage options may add flexibility to the energy system and ultimately allow RES surplus, still abundant even at the highest HP and EV shares with P2G/L systems included, to be further exploited. With this aim, battery storage systems as well as large centralized HP equipped with thermal storage units should be investigated as promising solutions.

Finally, CO_2 emissions have been divided by sectors and results are reported in Figures 3–6 for the most significant scenarios of the analysis. In the base case scenario, heating and transport account respectively for 42 and 39% of total emissions, confirming an interesting opportunity for sustainable low-carbon technologies to be applied in such areas of the energy system. In fact, when HP cover 60% of total thermal demand, CO_2 emissions related to heating can be reduced by 35 percentage points in their sectoral share (from 313.6 to 31.7 kt). A significant penetration of EV in private transport curbs CO_2 emissions by an additional 129 kt that, combined with the assumed increase in efficiency for freight vehicles, leads to an additional 145 kt reduction. The reduction in CO_2 emissions due to heating and transport sector electrification occurs at the price of an increase of 11 kt in the emissions related to the electricity generation sector. Production of synthetic gas brings about negligible results since HP are already covering 60% of heating demand for individual heating.

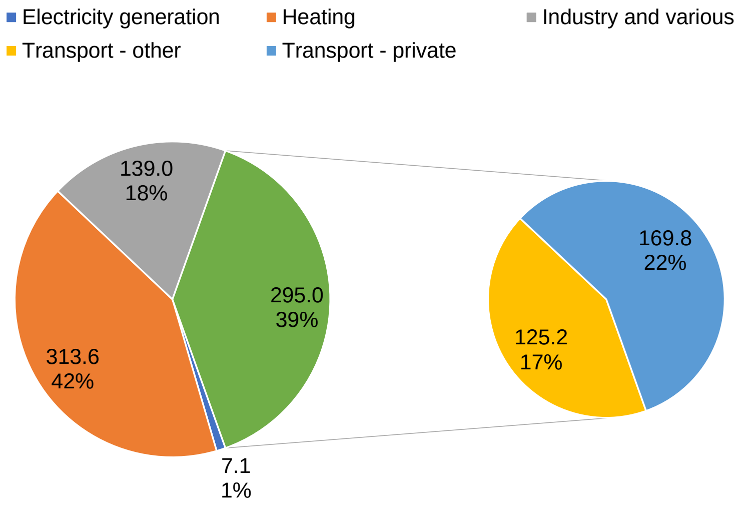

Figure 3: CO_2 emissions divided by sector - base case

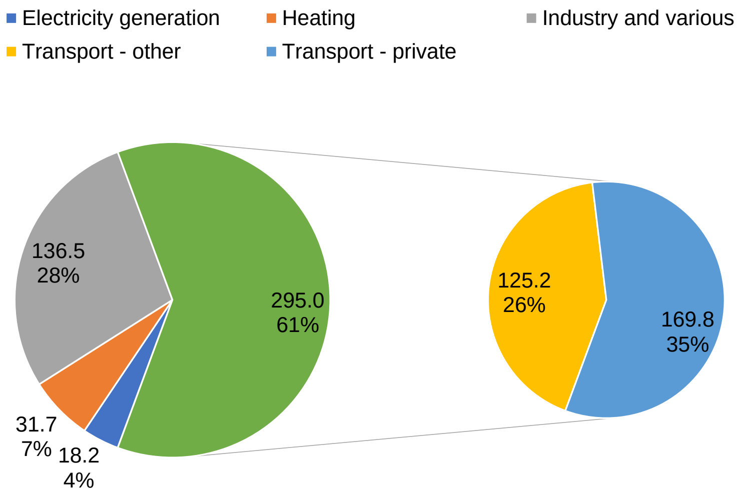

Figure 4: CO_2 emissions divided by sector - 60%HP + 0%EV

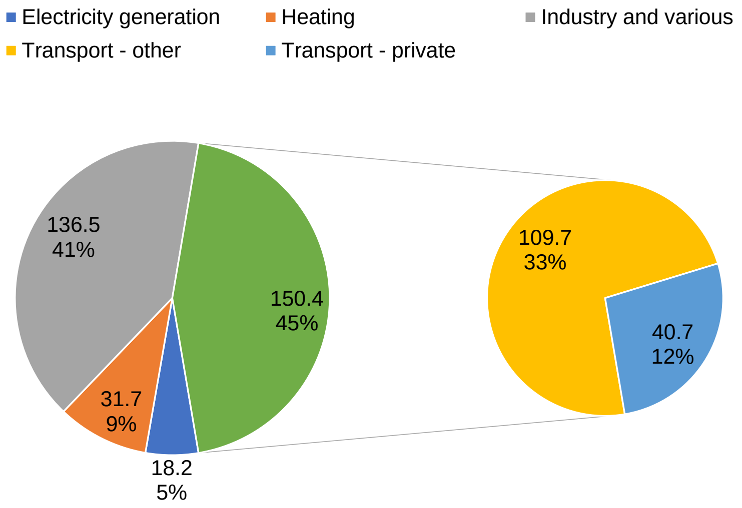

Figure 5: CO_2 emissions divided by sector - 60%HP + 80%EV

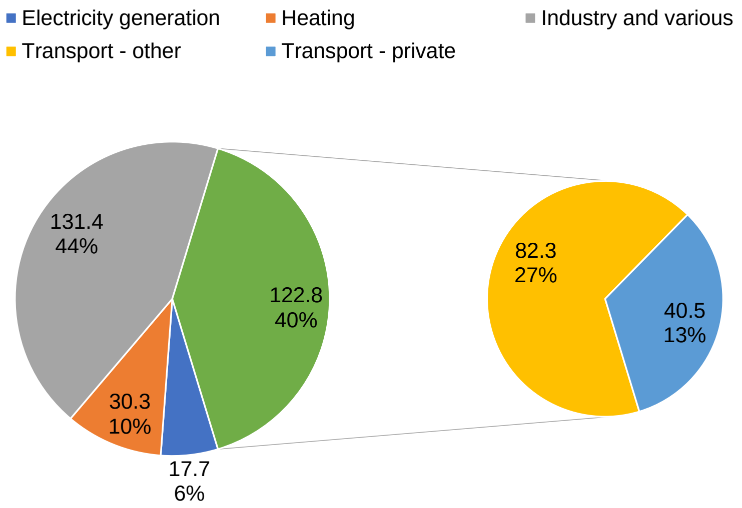

Figure 6: CO_2 emissions divided by sector - 60%HP + 80%EV + 25%P2G/L

The small variation observed in the "Industry and various" is due to gas losses, modelled in EnergyPLAN as a percent of total consumption.
It is worth mentioning that the objective of this paper is not eliminating current electricity

export towards a complete energy self-sufficiency; the electrification of the national energy system should be evaluated against the benefits achievable by developing stronger interconnections among neighboring regions, approach, this latter, extremely helpful in support of a larger RES deployment, by allowing RES overall availability to be conveniently shared among different countries. In this analysis, export is reduced only to assess hydroelectric generation potential to reduce emissions and improve RES utilisation.

4. Discussion

The results show an interesting potential to reduce the CO_2 emissions in the region, from 5 to 60% with respect to 2015 level. In particular, electricity generation from hydropower shows a lower variability and unpredictability than other RES that are usually available (i.e. wind and solar), in particular when some hydro dams are available. Although there are no pumping storage facilities, the four dams allow for a certain control over the power production. For this reason, electricity storage in support to the power grid has not been considered in this study but may add flexibility when the electrification of the energy system becomes significant, avoiding import from neighboring countries when renewable power is not available or not enough.

Although a significant amount of fossil fuel consumption may be replaced in this scenario, some uses remain, in particular in the transport sector. As confirmed by literature [28], freight transport is among the most difficult sectors for a low-carbon transition. Unless a strong shift towards rail transport across the Alps is reached, which is currently not properly being implemented, freight transport via trucks will remain a big concern to be addressed. While some manufacturers are already evaluating solutions to fully or partially decarbonise long haul freight transport (e.g. with hydrogen fuel cells, liquefied natural gas or synthetic fuel), their commercial availability is still limited. For this reason, only a strong international commitment can lead to a switch to low-carbon technologies. Among the possible solutions, in this study P2L technologies have been appraised revealing a further reduction in CO_2 emissions at the cost of strong reduction of potential renewable export.

The same consideration applies to light duty vehicles for the tourists that arrive in the region. Due to the international vocation of tourist flows, mainly driving from Italy, France and Switzerland, a strong international commitment towards low carbon solutions may be required to allow for a complete dismiss of oil-based fuel supply for transport. A mix of electricity, hydrogen and biofuels may be a solution, but proper infrastructures may be built and operated across Europe.

The decarbonisation of buildings heating via heat pumps and proper energy efficiency measures appears easier, since technological solutions are already available. The main barriers remain the will of performing investments from private citizens, although regulatory solutions and incentives are available. A non-secondary aspect is the behavior of the users, which is crucial to support proper energy savings in everyday operation of the heating systems.

5. Conclusions

This paper presents a case study of local energy planning applied to an Italian mountain region, where the abundant available hydropower is currently not fully exploited locally. While the electricity production comes almost totally from RES, other sectors are still strongly relying on fossil fuels, particularly on oil derivatives. Some future scenarios of increased electricity penetration in the buildings and transport sectors have been considered, to assess the potential benefits that can be obtained.

The results show that thanks to a penetration of heat pumps up to 60% of the heat demand, electric light duty vehicles up to 80% and P2G/L technologies replacing 25% of both natural gas for individual heating and diesel for heavy transport CO_2 emissions can be decreased up to -60%. The share of RES in final energy uses increases in all the scenarios, with a corresponding decrease of the exported electricity from hydro power. This decrease also includes a lowering producibility triggered by climate change issues impacting the local availability of water. The use of local electricity has the additional benefit of lowering the energy losses associated to its long-distance transport over high voltage lines but has to be evaluated against the benefits that an enhanced grid interconnection may bring about.

Future developments of this study may consider in greater detail some assumptions that have been currently performed, extending the analysis in the context of an environmental and techno-economic optimisation. In particular, alternative low-carbon options for long haul freight transport, other than P2L, will be considered, to estimate the potential decrease of the most significant share of remaining fossil fuel consumption.

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