Optimal management of renewable and fossil fuel energy systems in a smart community

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Abstract

The present paper focuses on the energy aspects related to sustainable communities aimed at becoming smart. In particular, the paper discusses optimal strategies for the management of renewable energy systems (RES) and fossil fuel energy systems. Marche Region, one of the 21 Italian administrative divisions, has been taken as a reference case in order to compare different strategies. The area is characterized by a high percentage of electricity imported from the grid, suggesting the importance of increasing the local production to become sustainable. The year 2020 has been taken as the target year. An energy model of the area has been built considering RES potential and energy saving initiatives defined in the Regional Energy Master Plan. The model has been developed with EnergyPLAN, an optimization tool developed by Aalborg University and used to assess energy systems Three different solutions for the integration of RES and the minimization of fossil fuel consumption have been considered: i) a Demand Side Management technique related to the introduction of heat pumps seeking to use the excess of electricity derived from renewable production; ii) the use of micro-CHP systems in buildings to compensate for the variability of RES production; iii) the introduction of EVs with dump and smart charge. The best results come from HPs and EVs with smart charge, which are able to reduce the electricity in excess and minimize the primary energy consumption, in particular when a high share of intermittent renewable is introduced.
Keywords: energy planning, renewable energy system, demand side management, heat pumps, electric vehicles, micro-CHP plants.

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1 Introduction

A smart community is defined as "a community in which government, business, and residents understand the potential of information technology, and make a conscious decision to use that technology to transform life and work in their region in significant and positive ways" [1].

The present paper focuses on the energy aspects related to smart communities, in particular, on optimal strategies for the management of Renewable Energy Systems (RES) and fossil fuel energy systems in sustainable communities. Optimal algorithms, indeed, must be introduced to control the supply and demand balance, with the aim at minimizing the entire energy consumption.

It is worth noting that researchers and policy makers have recently paid special attention to the role of cities and communities, from which the new energy paradigm takes origin [2]. Such interest has been also developed from the consciousness of the important contribution to GHG emissions coming from cities and the increase in urban population [3–6].

In Europe, it has motivated the launch of important European programs such as the 'Smart Cities and communities' initiative. The challenge, launched in 2011, initially covered only energy aspects; successively it was extended to include the transport and ICT sector with the launch of the European Innovation Partnership for Smart Cities and Communities in July 2012 [7]. Such initiative aims to overcome obstacles to the development of smart cities and communities, to co-fund demonstration projects and to help coordinate existing initiatives and projects.

To better face the challenge of creating a sustainable society, the introduction of distributed generation, in particular renewable generation together with an active demand response is unavoidable.

Renewable systems can be used both for thermal and electricity production, as well as for transports, but some of renewable sources are intermittent and not perfectly predictable, such as for PV and wind production. Consequently a high share of renewable requires the development of a more integrated energy system and high investment on ancillary resources to balance demand and supply at any time. In order to postpone investments in the existing grid, possible optimal strategies are the introduction of: i) micro-grids, which are able to internally compensate the variability coming from fluctuating renewable sources and ii) Demand Side Management, DMS, techniques, aimed at limiting the impact of the electricity in excess, through energy storage and an active response of energy demand. Micro-grids, in addition to renewable devices, can comprise storages, and micro-CHP systems fuelled by natural gas, which are able to compensate fluctuations [8].

The paper, as abovementioned, discusses optimal strategies for the management of energy systems in communities, which want to become smart. Strategies studied are the introduction of: i) micro-generation systems ii) heat pumps coupled to storage systems seeking to use the excess of electricity derived from renewable production and exported to the grid and iii) electric vehicles.

Marche Region has been taken as case study in order to compare different options. The region is one of the 21 energy divisions that need to fulfil emissions reduction derived by the Italian Burden Sharing. The latter is a mechanism according to which each administrative division must contribute to the EU challenging 2020 climate targets. The year 2020 has been, indeed, taken as reference year.

The renewable capacity installed together with the forecasted energy demand has been derived from the Regional Energy Master Plan, REMP and a recent communication, which has updated regional goals by 2020 [9, 10].

The present work is organised as follows: section 2 discusses the methodology used to build the energy scenario, section 3 focuses on the Marche Region Energy System, section 4 discusses and compares different energy strategies to integrate renewable sources and minimise the overall energy consumption.

2 EnergyPLAN

EnergyPLAN, a tool developed by Aalborg University to assess energy systems characterised by a high share of renewable sources, has been used to assess the above-mentioned strategies [11].

It is an optimization tool that can be used to assess energy systems on the basis of a regulation criteria defined by the user. It has been widely applied in literature to assess national, regional or local energy systems and to investigate the effects of introducing specific technology [12, 13].

All the energy demanding sectors are taken into account: industry, buildings and transport. An hourly distribution of the energy demand and supply must be defined, since an hourly balance is followed.

Examples of input data are: i) energy supply and demand of industry, buildings and transport sectors, ii) characteristics of the energy conversion devices and iii) installed capacity of renewable sources, RES.

The model provides also the possibility to introduce thermal or electrical storages in order to optimally operate the energy system.

The user needs to define the regulation strategy to be followed, which can be either technical or economic. For the present work the minimization of fuel consumption is followed. Furthermore the model allows the user to specify the regulation approach on the basis of which CHP and Heat Pumps, HP, systems and fluctuating renewable energy sources interact.

The outputs of the tool are energy consumption, CO_2 emissions and energy balance necessary to meet the energy demand on the basis of the regulation strategy implemented.

3 The Marche Region territory

3.1 Energy system analysis

The Marche Region is a small region in central-east Italy characterised by about one million and a half inhabitants. All the data shown in the present paragraph comes from the Regional Energy master Plan, REM, discussed in a previous paper written by the authors [9]. The REMP discusses low-carbon measures to be developed in the medium-term for both energy demand and supply, aimed at curbing regional greenhouse-gas emissions and establishes guidelines for governing those initiatives in the region.

Figures 1 and 2 show, respectively, the region's final energy consumption by sector and by commodity from 1988 to 2008. Fossil fuels cover a high percentage of energy consumption derived from a strong tertiarisation of the economy. Transportation and civil sectors are, indeed, the main end-users. Figure 2 shows a decrease in electricity consumption, in particular in industrial energy use, in 2008, due to the economic crisis. Agriculture and fishing, although traditionally relevant sectors for the economic activity of the region, have a marginal role, affecting about the 4% of total demand.

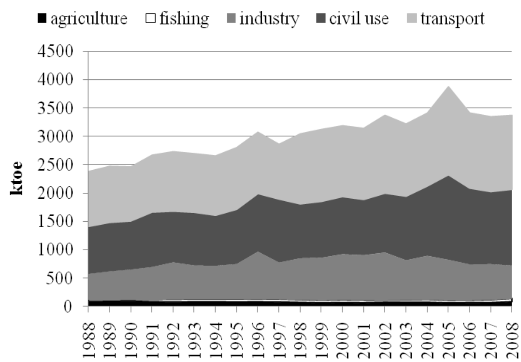

Figure 1: Regional final energy consumption by sector.

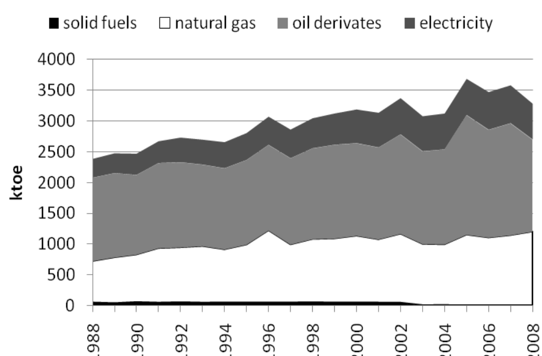

Figure 2: Regional final energy consumption by commodity.

Electricity production and consumption from 1973 to 2012 are shown in Figure 3. Almost 50% of electricity demand has been constantly satisfied by imports in the last ten years, although there has been a decrease in electricity demand from 2008. This is due to: i) the decrease in electricity production of one of the main thermal power plant of the region and ii) the reduction in the electricity production from the local hydroelectric production. It is worth noting that one of the REMP goals is to reduce this deficit, increasing the local production, in response to national government's recommendation (Law 239/2004 [15]), according to which regions have to look for a balance in their energy demand and supply. Currently, the electricity production from RES covers the 32% of regional demand. The renewable systems installed are PhotoVoltaic, PV, hydroelectric and biomass plants. No wind farms have been installed yet in Marche Region. Table 1 shows the capacity installed and the corresponding energy production in 2012. PV production is one of the main renewable sources in the territory, thanks to the highly remunerative Italian feed in tariff, which from 2007 has incentivised the widespread of this technology.

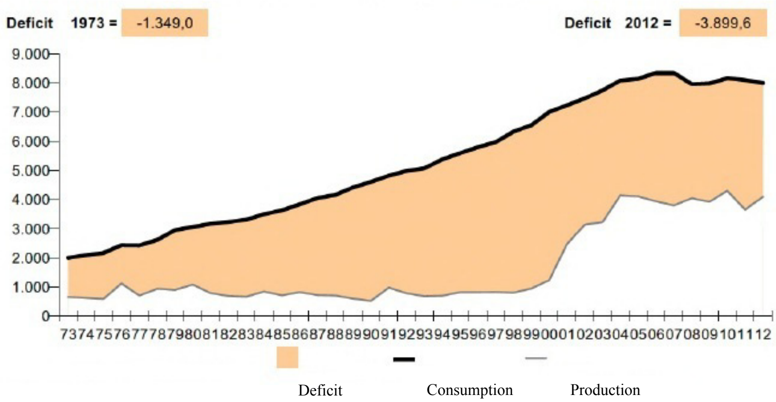

Figure 3: Regional electricity consumption and production [GWh].

Table 1: Renewable production.

	2012	
RES-E	Capacity [MW]	Production [GWh]
Hydroelectric	238.51	445.75
Biomass	24.01	102.45
Photovoltaic	786.59	658.38

3.2 Low-carbon initiatives and their effect on the final demand by 2020

Low-carbon measures discussed in the REMP and implemented in the energy model can be classified in three main groups aimed at rationalising demand-side energy use (first category) and improving regional power supply, assessing the introduction of distributed generation and removing the electricity deficit.

Table 2 presents a synoptic diagram of the energy-saving measures analysed together with the assumptions and the parameters used, more widely discussed in

Table 2: Assumptions and parameters used to assess energy saving measures.

Initiatives	Assumptions	Parameters used
Households:		
High-efficiency standard for new buildings	New buildings are the 0.8% of dwellings	0.004 toe/dwelling
Thermal insulation in private buildings	100 m^2 apartment Dwellings built before 1991	0.16 toe/dwelling
High-efficiency household equipment	110% refrigerator per dwellings 41.7% high-efficiency refrigerators installed so far	0.016 toe/dwelling
	37% washing machines per dwellings 38.9% refrigerators installed so far	
	100% dish machine per dwellings 32.2% high-efficiency dish-washing machine installed	
High efficiency lamp	Replacement of 2 lamps per dwelling 0.0115 toe/light_bulk	0.023 toe/dwelling
Tertiary sector:		
Thermal insulation in schools	Replacement of single-glazed window with double-glazed window Thermal-insulation parameters defined by Law 192/2005 [18] and Decree 311/2006, 59/2009 [19, 20] Applications of the Best Available Techniques and materials	30% energy reduction of thermal demand
High-efficiency lamp in public lighting and traffic lighting	Replacement of 150 W High-Pressure Sodium Lamp, HPS, with 60 W LED (4000 operation hours)	0.06 toe/year/lamp
	Replacement of 60 W incandescent light bulk with 16 W LED (4000 operation hours)	0.04 toe/year/lamp
Industry:		
Electricity reduction in industry (inverters, high-efficiency electric motors, high-efficiency lamps)	Industry consumption distribution: 4% lightings, 75% electric motors, 21% process Penetration factor for high-efficiency lighting, high efficiency motors and inverters, of 57%, 33% and 33% [21]	17.8% of electricity consumption
Energy production from biomass	Wood-waste recovery from industry Modernisation of existing plant to exploit wood wastes	-

Table 2: Continued.

Initiatives	Assumptions	Parameters used
	Transport:	
Promotion of less polluting cars	In application of EU Regulation 443/2009 [22], within the 2020 emission limit of the average car sold to 130 g CO_2/km by 2015 and 95g CO_2/km in 2020.	-
Interventions for sustainable mobility and public transport	Reduction of systematic trips home – work and home – school within the regional and municipal territory.	-

Table 3: Energy demand by 2020 [ktoe].

Electricity	745
Heating	
Buildings	939
Industry	414
Transport sector	1,166

previous paper written by some of the authors [14]. Table 3 shows the resulting energy demand, implemented in the 2020 regional energy scenario.

It can be observed that the civil sector and, particularly, the households have many initiatives for the energy-saving measures because, in this sector the regional government has greater decision-making power. In particular, the major contribution derives from thermal-insulation initiatives because most of the buildings in the Marche Region were built before the introduction of important energy-efficiency criteria in the building sectors [16].

Transport is another important sector for energy-savings; the promotion of less polluting cars is an important initiative considered in the model defined on parameters discussed in the Italian Energy Efficiency Plan [17].

3.3 Renewable sources by 2020

A main distinction must be done between RES-E, renewable electricity and RES-H, renewable heating. Table 4 shows the RES capacity and corresponding production by 2020.

As regards RES-E, the increase in hydroelectric production can more likely derive from micro and mini-hydroelectric plants, since there are no areas suitable to install big plants. As discussed in [23] electricity production from biomass can play an important role in Marche Region, with a positive side effect on agriculture sector, thus an interesting contribution can come from this source by 2020. It has been assumed a low increase in PV production, due to the termination of the national supporting scheme.

As regards wind production, it has been assumed to install a low capacity in the near future, due to non-technical problems (i.e. opposition of Green Movement due to change in rural landscape) that have limited its widespread so far. RES-H are currently less developed RES-E, but in line with the Italian Energy Strategy, they are expected to play a central role in order to reach 2020 EU climate targets. RES-H sources comprise biomass and solar heating.

Table 4: RES capacity and production by 2020.

	Capacity [MW]
PhotoVoltaic	1,218
River Hydro	152
Wind	175
Biomass	45
Solar heating	2

3.4 Simulation results of the 2020 regional energy scenario

Table 5 shows the energy scenario resulting from the 2020 scenario implemented. It can be seen that thanks to the introduction of a high share of renewable energy there is a reduction in the electricity import with respect to 2012.

Furthermore during summer, part of the electricity produced by PV needs to be exported, since it is not contemporary to the energy demand.

Table 5: 2020 reference scenario.

	Internal production	Import
Coal [TWh/y]	1.18	1.67
Oil [TWh/y]	13.12	0.85
NG [TWh/y]	17.83	4.06
Biomass [TWh/y]	3.26	0.31
Other RES [TWh/y]		
Total [TWh/y]	38.10	6.89
CO_2 Emissions [Mtoe]*	7.57	
Electricity imported [TWh/y]	3.22	
Electricity exported [TWh/y]	0.06	
RES share on primary energy [%]	15.6	
RES share on electricity demand [%]	33.6	
Electricity from RES [TWh/y]	2.7	

*Excluding CO_2 emissions derived from import

For example, Figure 4 shows a day in July, when part of the electricity produced by RES needs to be exported. In order to avoid this problem it is necessary to reduce the “electricity in excess”, defined as the electricity produced by RES which is not directly used by the local community and therefore fed to the general grid. Furthermore the introduction of a high share of renewable creates grid stability problems. The following paragraph deals with optimal strategies to avoid the above-mentioned concerns.

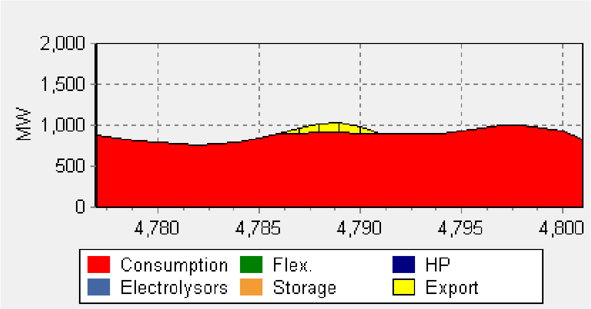

Figure 4: Electricity consumption and export in a day of July [GWh].

4 Optimal energy strategies

As previously introduced, the present paragraph investigates optimal management strategies that allow the local grid to act as Smart Grid without heavy investments to adapt the general grid for the introduction of a high share of renewable sources.

Three solutions for better integrate renewable have been considered: i) the introduction of DSM techniques related to the introduction of heat pumps to satisfy the heat demand of buildings, iii) the use of micro-CHP systems in the building sector and ii) the introduction of EVs. As regards the regulation strategy in EnergyPLAN model, a technical optimization aimed at reducing the fuel consumption balancing both thermal and electricity demand has been followed.

In the present study heat pumps are used to satisfy the heat demand in the building sector, seeking to use the excess of electricity derived from renewable production and exported to the grid. It is assumed to cover 3 GWh of heating demand in buildings that corresponds to the 28%, which is a reasonable value.

Table 6 shows the main results. HPs provide a decrease in fuel consumption, consequently in CO_2 emissions, the electricity import increases and there is a slight decrease in the electricity excess produced by RES and exported to the grid. This is due to the fact that the main excess coming from RES derives from PV production and it mainly occurs in summer period, while it has been assumed to use heat pumps only for thermal demand. In order to reduce such export, HPs should be applied to satisfy also the cooling needs. The introduction of micro-CHP, as expected, provides a reduction in import, thanks to the electricity internally produced. The local fuel consumption increases due to the need of natural gas for feeding such systems, but the overall CO_2 emissions decreases since energy needs are satisfied in a more efficient way. As regards Electric Vehicles (EVs), it has been assumed to completely replace vehicles fuelled by petrol. Two charging typologies have been chosen: i) dump charge and ii) smart charge. In the 'dump charge' the user defines the time for recharging vehicles (a constant recharge from 10 p.m to 7 a.m. has been assumed) and the electricity demand is summed to the electricity demand of the area. In case of 'smart charge', EVs are used to store the electricity produced by intermittent renewable sources and reduce the excess of electricity exported to the grid. The excess of the electricity, as shown in Table 6, consequently decreases. The introduction of EVs increase the import and reduce the overall CO_2 emissions.

Table 6: Results derived from different strategies.

	Fuel consumption excl RES [TWh/y]	CO_2 without import [Mton/y]	CO_2 with import [Mton/y]	Electricity excess [TWh/y]	Import [TWh/y]
BAU	38.10	7.57	9.27	0.06	3.22
HPs	34.88	6.94	9.13	0.05	4.19
Micro-CHP	39.00	7.74	8.85	0.06	2.06
EV dump charge	35.30	6.83	8.94	0.06	4.02
EV smart charge	35.20	6.81	8.94	0.01	4.02

In the 2020 scenario analysed, Marche Region continues to import electricity, suggesting the possibility to increase local generation. In order to appreciate the effect of the solutions studied, when the RES production from intermittent sources increases, Figure 5 and 6 show the effects of the strategies proposed on fuel consumption excluding RES. In case of a high PV and wind production the best results come from HPs and EVs with a smart charge.

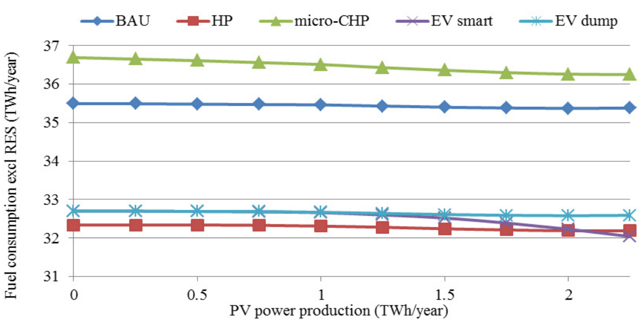

Figure 5: Fuel consumption excluded RES at different PV power production.

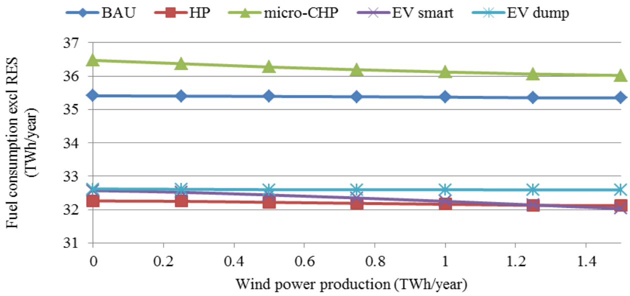

Figure 6: Fuel consumption excluded RES at different wind power production.

5 Conclusions

Taking as reference case a sustainable community that aims to become smart, different optimization strategies for integrating a high share of renewable intermittent sources have been studied. Since the area analysed imports a high quantity of electricity, the introduction of a high share of RES-E could help to make the area sustainable. Optimally managing the energy system characterised by a high share of RES provides a reduction in the overall fuel consumption and CO_2 emissions. The best strategies appear to be the introduction of HPs, to be used for satisfying both thermal and cooling needs, together with the introduction of EVs with a smart charge.

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