Journal of Physics:
Conference Series

PURPOSE-LED
PUBLISHING™

PAPER • **OPEN ACCESS**

Potential Role of green hydrogen as an energy carrier in smart energy system communities

To cite this article: Ali Mojtahed *et al* 2023 *J. Phys.: Conf. Ser.* **2648** 012096

Potential Role of green hydrogen as an energy carrier in smart energy system communities

Ali Mojtahed*[1], Alessandro Ciancio[1], Antonio Sgaramella[1]

Corresponding author :Ali.mojtahed@uniroma1.it

1 Department of Astronautical, Electrical and Energy Engineering, Sapienza University of Rome, Via Eudossiana 18, 00184, Rome, Italy

Abstract. Smart energy systems refer to the use of advanced technologies and systems to optimize the generation, distribution, and consumption of energy. The main goal of such a concept is to create an intelligent energy infrastructure based mostly on sustainable solutions namely renewable generations. Notwithstanding, renewable energy resources by their nature are unprogrammable. The main challenge is to balance properly the demand and supply curve To do so, various interventions should be employed to improve the reliability of the system (*namely*: real-time energy consumption monitoring to optimize energy efficiency and integration of energy storage systems). The final outcome is significant energy saving as well as cost reduction and cutting carbon footprint.
Hydrogen is mostly refers to as 'future fuel' due to its marvellous properties. It is an energy carrier that is characterized by water and heat as byproducts of combustion. Furthermore, it can be used in a variety of applications, including transportation, power generation, and industrial processes. It can be used in fuel cells to power electric vehicles or blended directly with natural gas to reduce GHG emissions. The current work investigates the potential role of Hydrogen inside a smart energy system on a community scale. Various contributions are defined for Hydrogen inside a community featuring power to gas, power to vehicles or blending into NG. The layout is composed of hybrid electric, thermal and cooling power generation which is integrated with storage systems. At the end of the simulation, various scenarios are compared to each other in terms of energy performance, economic indicators and environmental impacts to carry out the best suitable option.

1. Introduction

The concept of energy distribution systems has changed gravely in the past decade[1,2]. Inside the European Union, the target is to reduce GHG emissions by 15 % in 2030. In order to reach such a target, the energy policies must adapt new solutions to replace existing ones [3]. The change has already started with the introduction of the smart grid to increase the reliability of electric disposition as well as adapting environmentally friendly technologies. Such a concept is developed in order to replace conventional fossil fuel power plants with non-centralized small-generation ones that are dedicated to the district or a few blocks of residential units [4]. In this new scenario, the role of renewable sources such as photovoltaic, wind and urban refutes are promoted and become one of the main components of the smart grid community. Additionally, the customers, sometimes referred to as nodes, are no longer passive clients who only consume electricity. Instead, they can also produce electricity and import it to the grid. In this case, they are known as "prosumers" who can interact with the network in a bi-directional way [5]. The communication between communities to share surpass production can also be feasible through the definition of a bigger society involving several energy communities.
The concept can be expanded beyond only the electricity grid, to thermal and /or cooling and potentially, the gas network in share within the community level. In order to achieve such a network, various energy

storage systems should be defined to store surplus energy generation in the short and long-term periods. It is well proven that in order to reach a hight efficient and flexible energy system, coupling and interaction between energy sectors is crucial [6]. This approach is considered as a milestone for the growth of new-born concepts such as power to heat, power to gas , power to X [7] and other innovative technologies to be employed in multigeneration scenario.

Hydrogen is referred to as the "fuel of the future" due to its features as an energy carrier with zero GHG emissions, has gained progressive attention in the energy market [8–10]. As of today, most mature technologies are recognized to be Alkaline and Proton exchange electrolysers that operate at lowtemperature up to 70°C. The high temperature electrolysis present higher efficiency however, shorter stack lifetime as well as significant capital cost prevents further developments. The application of High temperature electrolysis can be justified through hybrid layouts to split the capital cost and at the same time improve production rate [11]. Hydrogen can be considered an effective solution to store surplus renewable energy incomes[12]. In this case, the final product is known as "green Hydrogen". As discussed in [13], the hydrogen could play an important role to reduce the natural gas consumption in the near future. There are several sectors that the application of Hydrogen can be defined inside the community:

1. To supply the fuel cell to regenerate electricity during the black hours.
2. Direct application in the transportation sector as a fuel for hydrogen vehicles. or blending into natural gas as a feedstock to produce synthetic fuels [14].
3. Thermal energy production through blending into natural gas in order to reduce CO_2 emissions[15].
4. Power generation as the feedstock of gas turbines or hydrogen turbines. This can provide a flexible and low-carbon option for power generation, especially when combined with carbon capture and storage (CCS) technologies [16].
5. Synthesis of methane through undergoing the chemical reaction with CO_2 (Sabatier reaction)[17].

Having mentioned all that, the present work investigates the potential production of the hydrogen from the surpass renewable generation inside the energy community system. The case study is built assuming thermal, cooling and hydrogen network in share in addition to the electricity network which are integrated with the existing local electricity grid and natural gas grid. Renewable generation is also taken into account. Beside the hydrogen, there are several other storage options that have been considered for thermal and electric surplus generation. The aim is to deploy a self-consumption solution in community level as much as possible and conserve the excess generation through various storage systems within the community. Figure 1, provides a schematic scheme of extension idea of the smart energy system.

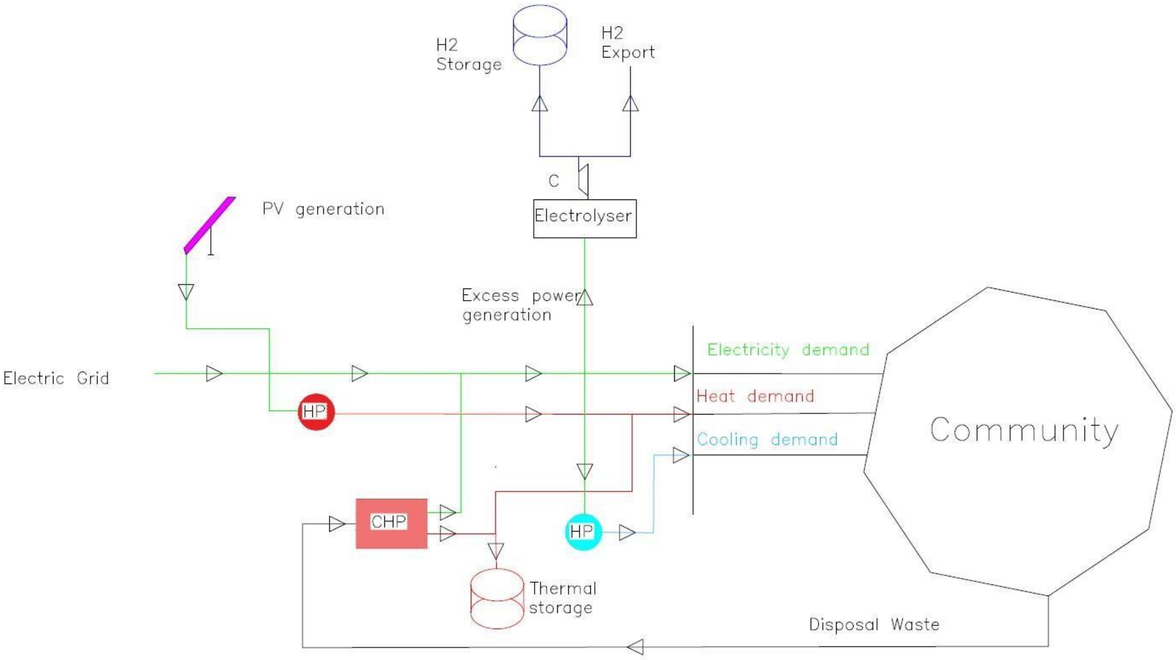

Figure 1- Schematic deagram of the energy community

2. Methodology

A residential unit consist of two hundred flat in the city of Rome is set as the case study. The characteristics of the demand curve for electric, heating and cooling load is set based on the study performed in[18,19]. Table 1 summarizes the main features of the case study..

Building type	Number of units	Number of Habitants	Surface (m^2)	Annual electric consumption (MWh/year)	Annual heating consumption (MWh/year)	Annual cooling consumption (MWh/year)	Municipal waste production (tons /year)
Residential	200	600	20000	1780	2344	1000	695

As shown also in table 1, the municipal waste production is taken into consideration to perform both electric and thermal recovery from waste. This concept would be explained in details in the following section.

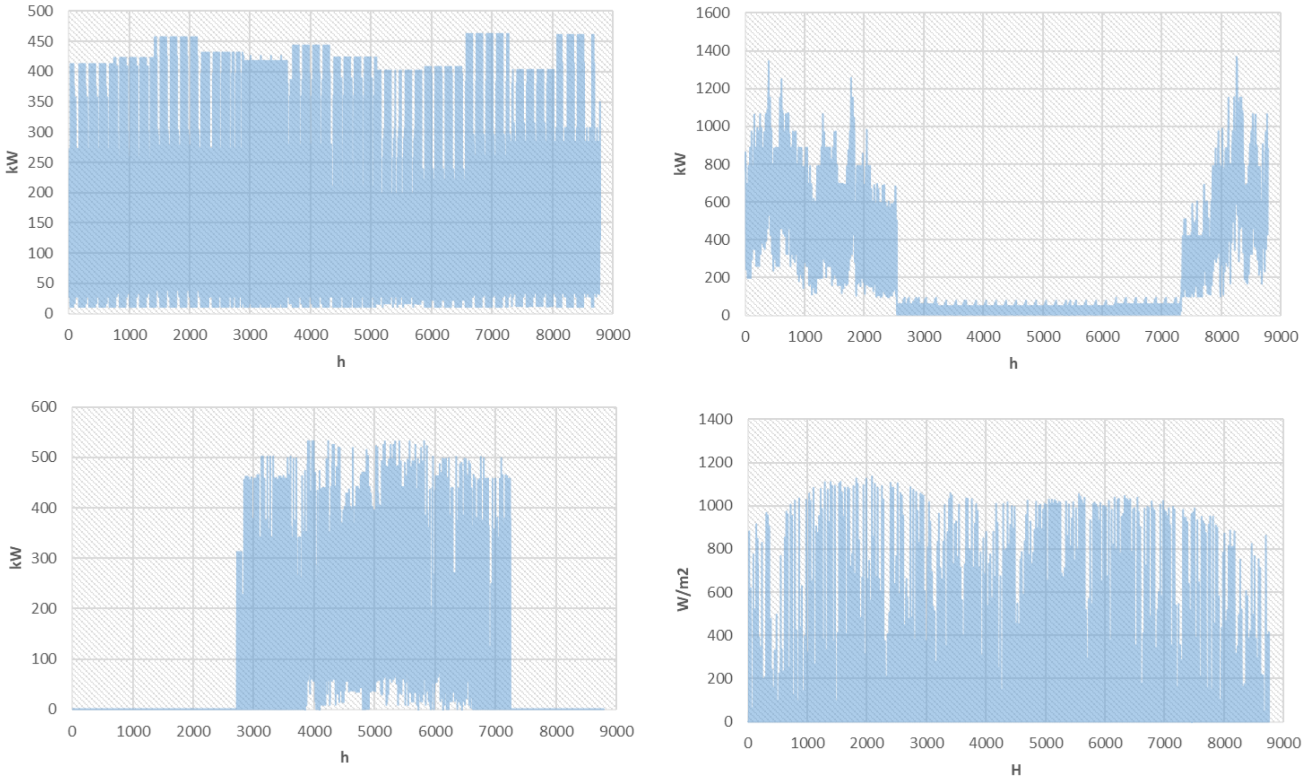

Figure 2_ a)Electric demand; b) Heating demand; c) Cooling demand ; d) Solar radiation of the Rome

The energy recovery from the municipal solid waste (MSW) can be performed by estimating the methane production characteristics of the organic fraction (OF). Such value varies based on the humidity percentage as well as the collection type of the disposal. Table two provides the bio methane production percentage for three type of disposal treatment: Mechanically separation (MS), Sewage sludge (SS) and Separately collection (SC)[20]:

Table 1- CH_4 estimation of MSW [20]

Method	Total Solids (%) (TS)	Total Volatile solids (%TS) (TVS)	m^3 CH_4/kg TVS
MS	66.5	53	0.30
SS	20	80	0.45
CS	16	79	0.5

2.1 The smart energy community

The concept of Power to gas is integrated with the smart energy systems in order to increase community self-consumption ratio instead of direct renewable electricity injection to the national grid [21]. The proposed layout considers cogeneration solutions to answer three different demand namely electric, heating and cooling load of the community .In this case, renewable generation from photovoltaic installation and disposal production inside the community has been used as the main sources of energy generation. The community however, remains connected to the national electricity grid to receive additional electricity during the blackout hours. The heat demand is responded with the installation of a heat pump unit supplied with PV generation. In addition, a genset supplied with organic solid waste (OSW), capable of heat recovery is set to provide a portion of thermal demand as well as electric ones. The residual heat is stored within the community via a vessel.

The role of Hydrogen is defined to recover excess renewable generation that remain without application. Such green Hydrogen ensures long period storage of energy and can be exported out of the community. Hydrogen that is exported to the outside of community can be a proper solution to reduce natural gas consumption in a short period [22]. Table.2, illustrates the main assumptions of the system for simulation part. The energy model is carried out inside the EnergyPLAN environment.

Table 2- Energy input of the community

Total electricity demand	1708	MWh
Total heat demand	2345	MWh
Total cooling demand	697	MWh
Total disposal waste	695	Tons
Total waste energy recovery	806	MWh
Electric waste recovery	322	MWh
Thermal recovery	363	MWh
PV size	900	kW
PV input	1140	MWh
Grid import	427	MWh
Electrolyser	400	kW

3. Results and Discussion

Figure 3 and 4, provide the monthly report of energy balance of the system for the months of July (Summer) and January (Winter). As anticipated, the PV income reaches its peak during the summer time. In July for instance, the ratio between PV generation and the imported electricity from the grid is equal to 3.48. 60 % of excess PV production in this case, is dedicated to produce Hydrogen from electrolysers. The total H_2 production is equal to 9 tons per year. In which the half is exported. Through H_2 production from excess renewable available, 304 MWh energy is recovered. However, as can be seen in Figure 5 and 6, still more energy can be recovered from RES. In this case larger electrolysers can be employed to the system.

On the other hand, during the winter time, by shrinking RES productivity, the dependency of the system to the grid rises up. As a result, in January the most of the electricity, for both heat pump and electric consumption is provided form the grid. The PV generation ratio to grid electricity in this particular month is equal to 0.64. As suggested by results, around 90% of the heat demand is provided from the centralized Heat pump. This is due to the limited waste input of the community that could only response to the 10 % in average.

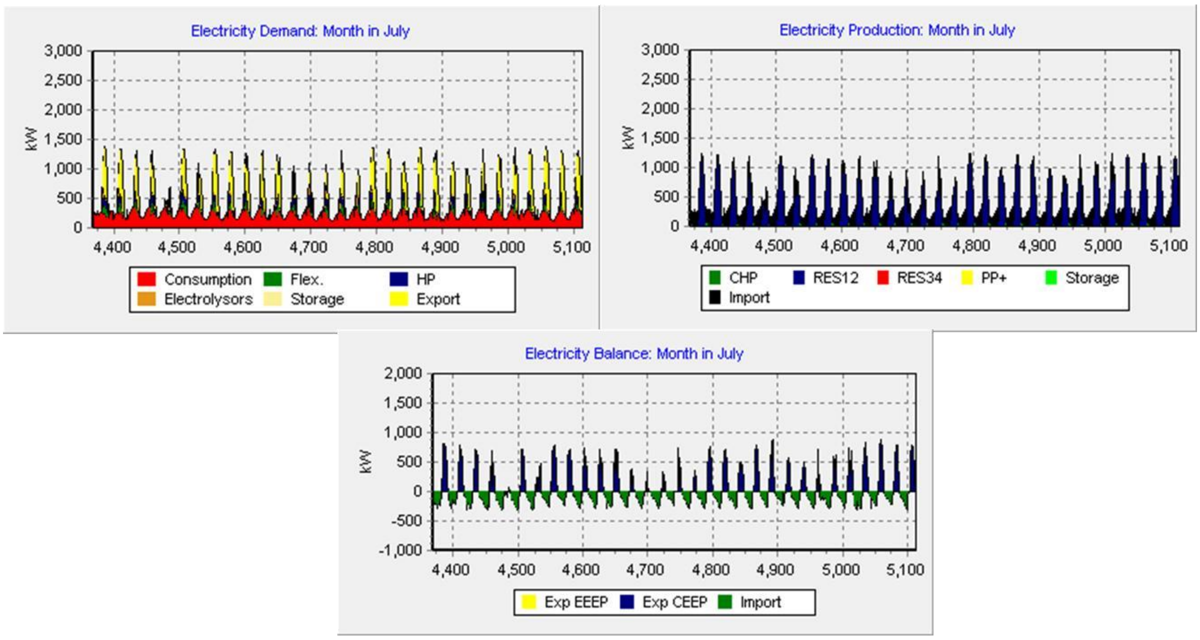

Figure 3- The simulation results of July

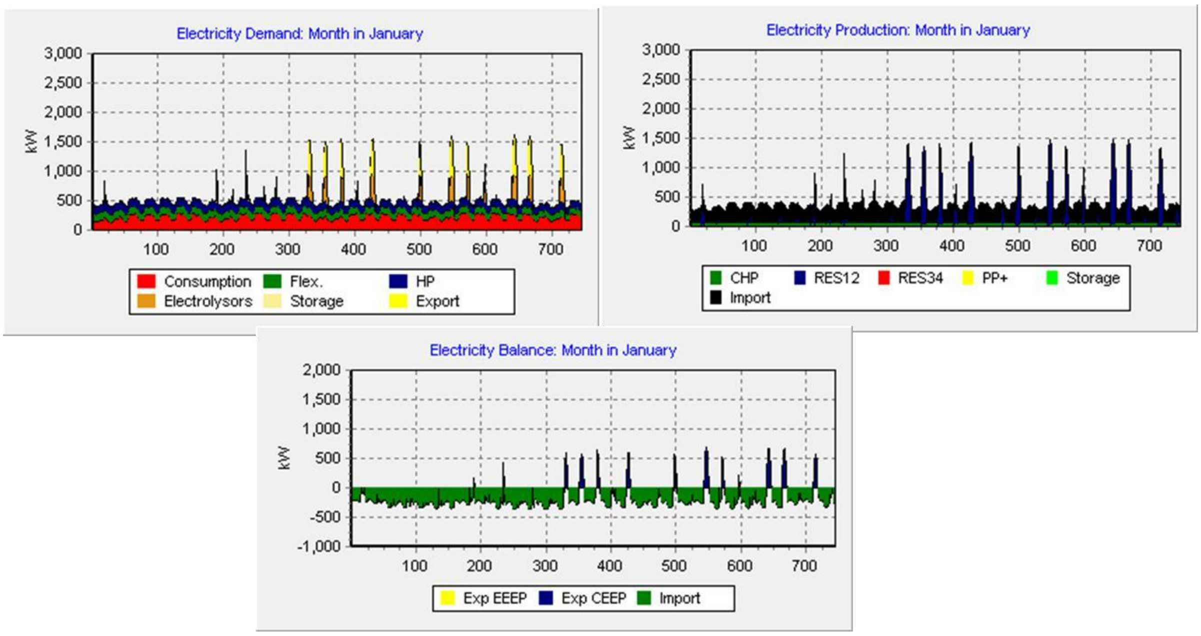

Figure 4- The simulation results of January

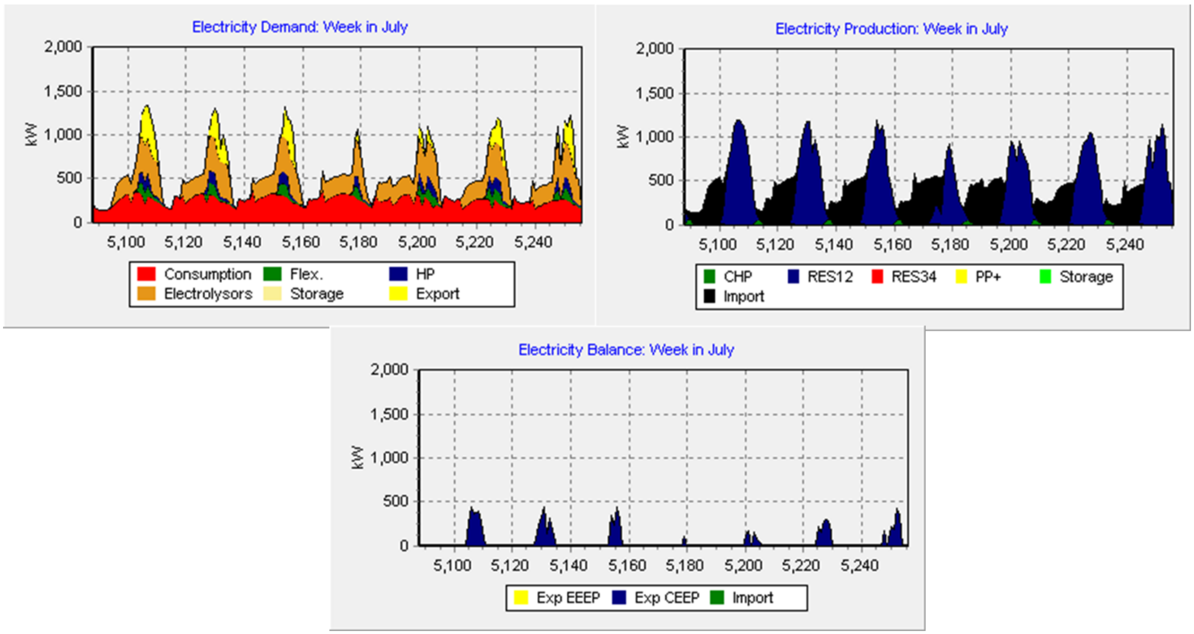

Figure 5- Simulation results of a week in July

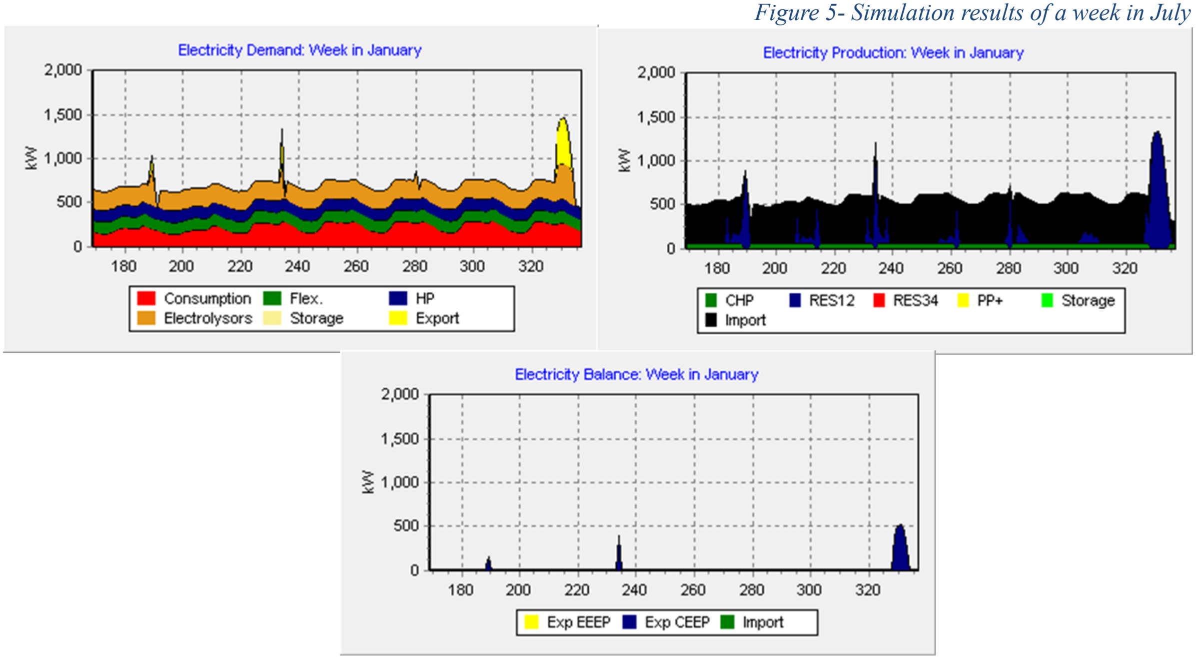

Figure 6- Figure 7- Simulation results of a week in July

In overall, the main Hydrogen production is executed during the summer time due to the huge excess PV generation. By fixing the annual export of 4.5 tons H_2/year, still depending on the size of electrolysers, some additional RES energy is available that can be used to store the H_2 within the community. It is noteworthy that the export value is the sum of all months calculated based on equivalent hours that PV available. It is different for each month. As can be seen in Figure 7, the H_2 storage in order to minimize the RES export can be up to 18 tons /year. In this case, 100% of Renewable electricity is conserved within the community and there is zero injection to the grid. This results can be meaningful by acknowledging the fact that in near future, the almost all the renewable power generated must be self-consumed.

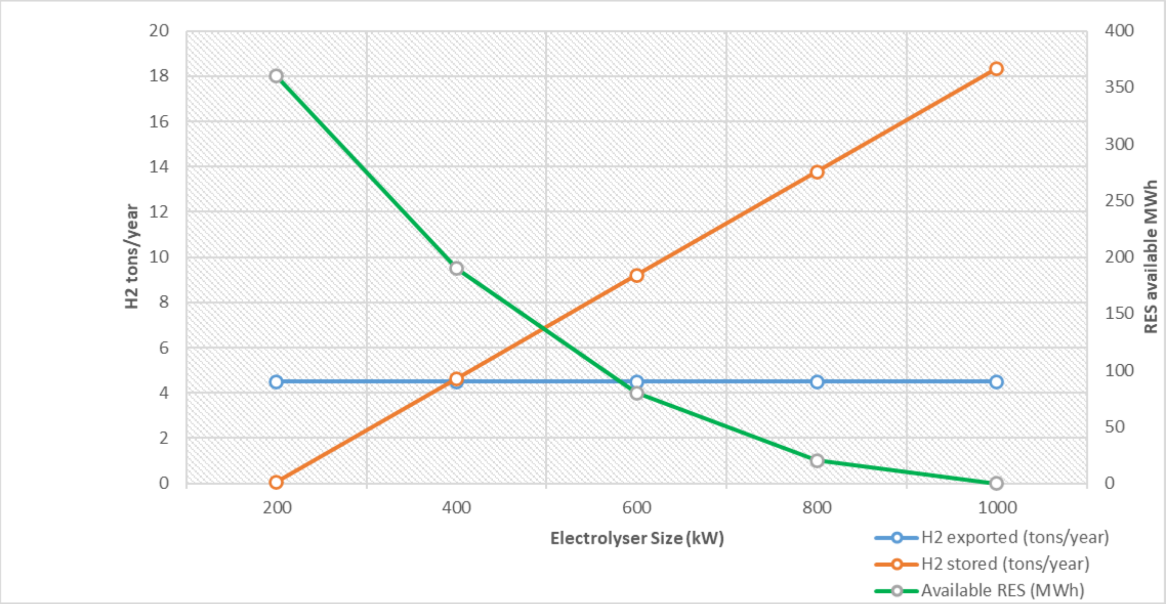

Figure 8- Sensitivity analysy on the size of electrolyser

4. Conclusion

The conventional energy systems are formed based on energy sectors separation. In this case, any supplies deals with only one type of demand at the time. In contrast, in smart energy systems, the collaboration among multigeneration sources is determined to improve the energy efficiency by employing co and multi generation solutions. This work investigated a smart energy system configuration in which electric, thermal and cooling demand are provided in a community level. A gridconnected case integrated with solar photovoltaic generation and waste energy recovery treatments. Furthermore, H_2 production in such a community is evaluated in order to conserve excess RES generation. As the results showed for PV installation equal to 900 kW, after consumption inside the community, at least 9 tons of H_2 /year can be produced. In case that all the excess PV generation is dedicated to H_2 production, such a value reaches around 23 tons H_2/year. In the near future, energy communities might play a more important role in the global energy market. As a result, several different storage systems should be employed simultaneously in order to increase the efficiency of system. Of course H_2 production can be considered as one of the options that can be applied for several usages within and beyond the community itself.

References

[1] Lo Basso G, Pastore LM, de Santoli L. Power-to-Methane to Integrate Renewable Generation in Urban Energy Districts. Energies 2022;15. https://doi.org/10.3390/en15239150.

[2] Lo Basso G, Mojtahed A, Mario Pastore L, De Santoli L. High-efficiency solution for an openloop desiccant assisted solar cooling system by integrating trans-critical CO2 heat pumps: A comprehensive techno-economic assessment. Energy Convers Manag X 2023;20:100437. https://doi.org/10.1016/j.ecmx.2023.100437.

[3] Pastore LM, Lo Basso G, Cristiani L, de Santoli L. Rising targets to 55% GHG emissions reduction – The smart energy systems approach for improving the Italian energy strategy.

Energy 2022;259. https://doi.org/10.1016/j.energy.2022.125049.

[4] de São José D, Faria P, Vale Z. Smart energy community: A systematic review with metanalysis. Energy Strateg Rev 2021;36. https://doi.org/10.1016/j.esr.2021.100678.

[5] Mamounakis I, Vergados DJ, Makris P, Varvarigos E, Mavridis T. A Virtual MicroGrid platform for the efficient orchestration of multiple energy prosumers. ACM Int Conf Proceeding Ser 2015;01-03-Octo:191–6. https://doi.org/10.1145/2801948.2802012.

[6] Pastore LM, Basso G Lo, Santoli L De. Can the renewable energy share increase in electricity and gas grids takes out the competitiveness of gas-driven CHP plants for distributed generation ? Energy 2022;256:124659. https://doi.org/10.1016/j.energy.2022.124659.

[7] Pastore LM. Combining Power-to-Heat and Power-to-Vehicle strategies to provide system flexibility in smart urban energy districts. Sustain Cities Soc 2023;94. https://doi.org/10.1016/j.scs.2023.104548.

[8] Uyar TS, Beşikci D. Integration of hydrogen energy systems into renewable energy systems for better design of 100% renewable energy communities. Int J Hydrogen Energy 2017;42:2453–6. https://doi.org/10.1016/j.ijhydene.2016.09.086.

[9] Lo Basso G, Pastore LM, Mojtahed A, de Santoli L. From landfill to hydrogen: Technoeconomic analysis of hybridized hydrogen production systems integrating biogas reforming and Power-to-Gas technologies. Int J Hydrogen Energy 2023:1–18. https://doi.org/10.1016/j.ijhydene.2023.07.130.

[10] Ciancio A, De Santoli L. Assessing the Levelized Cost of Hydrogen Production in a Renewable Hydrogen Community in South Italy. Proc - 2023 IEEE Int Conf Environ Electr Eng 2023 IEEE Ind Commer Power Syst Eur EEEIC / I CPS Eur 2023 2023:1–6. https://doi.org/10.1109/EEEIC/ICPSEurope57605.2023.10194654.

[11] Mojtahed A, De Santoli L. Hybrid Hydrogen production: Application of CO2heat pump for the high-temperature water electrolysis process. J Phys Conf Ser 2022;2385:0–8. https://doi.org/10.1088/1742-6596/2385/1/012053.

[12] Lo Basso G, Mojtahed A, Pastore LM, De Santoli L. High-temperature green hydrogen production: A innovative– application of SOEC coupled with AEC through sCO2 HP. Int J Hydrogen Energy 2023:1–16. https://doi.org/10.1016/j.ijhydene.2023.04.231.

[13] Pastore LM, Mojtahed A, Santoli L De. How Power-to-Gas strategy could reduce national Natural Gas consumption over the energy crisis period. J Phys Conf Ser 2022;2385. https://doi.org/10.1088/1742-6596/2385/1/012102.

[14] Sgaramella A, Lo Basso G, de Santoli L. How the cylinder initial conditions affect the HCNG refuelling process - A thermodynamic analysis to determine the most effective filling parameters. Int J Hydrogen Energy 2023:1–17. https://doi.org/10.1016/j.ijhydene.2023.07.323.

[15] Lo Basso G, Pastore LM, Sgaramella A, Mojtahed A, de Santoli L. Recent progresses in H2NG blends use downstream Power-to-Gas policies application: An overview over the last decade. Int J Hydrogen Energy 2023:1–30. https://doi.org/10.1016/j.ijhydene.2023.06.141.

[16] de Santoli L, Lo Basso G, Barati S, D’Ambra S, Fasolilli C. Seasonal energy and environmental characterization of a micro gas turbine fueled with H2NG blends. Energy 2020;193:116678. https://doi.org/10.1016/j.energy.2019.116678.

[17] Districts E. Energy Districts 2022.

[18] Pastore LM, Basso G Lo, Ricciardi G, Santoli L De. Smart energy systems for renewable energy communities : A comparative analysis of power-to-X strategies for improving energy self-consumption 2023;280.

[19] Mancini F, Romano S, Basso G Lo, Cimaglia J, De Santoli L. How the italian residential sector could contribute to load flexibility in demand response activities: A methodology for residential clustering and developing a flexibility strategy. Energies 2020;13. https://doi.org/10.3390/en13133359.

[20] Tyagi VK, Fdez-Güelfo LA, Zhou Y, Álvarez-Gallego CJ, Garcia LIR, Ng WJ. Anaerobic codigestion of organic fraction of municipal solid waste (OFMSW): Progress and challenges. Renew Sustain Energy Rev 2018;93:380–99. https://doi.org/10.1016/j.rser.2018.05.051.

[21] Pastore LM, Lo Basso G, Ricciardi G, de Santoli L. Synergies between Power-to-Heat and Power-to-Gas in renewable energy communities. Renew Energy 2022;198:1383–97. https://doi.org/10.1016/j.renene.2022.08.141.

[22] Pastore LM, Lo Basso G, de Santoli L. Towards a dramatic reduction in the European Natural Gas consumption: Italy as a case study. J Clean Prod 2022;369. https://doi.org/10.1016/j.jclepro.2022.133377.