Spatial-based scenario analysis for the smart energy transition

Valentina D'Alonzo[1], Daniele Vettorato[2], Pietro Zambelli[3]

[1] *University of Trento, Department of Civil Environmental and Mechanical Engineering, valentina.dalonzo@unitn.it; Eurac Research, Institute for Renewable Energy, valentina.dalonzo@eurac.edu*
[2] *Eurac Research, Institute for Renewable Energy, daniele.vettorato@eurac.edu*
[3] *Eurac Research, Institute for Renewable Energy, pietro.zambelli@eurac.edu*

Abstract: Scenario analysis is a particularly interesting tool for the smart energy transition of cities and regions. It allows understanding the possible futures of an energy system with and without the implementation of strategic actions and under different conditions. The presented study deals with the development of alternative scenarios for the energy system of Valle d'Aosta region (Italy) and is aimed at suggesting sustainable pathways for its energy transition. In particular, the strategic actions want to foster the exploitation of Shallow Geothermal Energy (SGE), a renewable source still not exploited adequately in spite of its great potential to increase the energy efficiency in buildings. Two driving forces establish the base for the scenario development. They are: 1) using SGE for supplying the space heating demand of residential buildings, replacing some fossil fuels; 2) refurbishing part of the residential building stock for decreasing its thermal demand. Different combinations of these two drivers shape the developed scenarios, which are then analysed through some indicators. All the data processing is done following a spatially explicit approach. This GIS-based scenario analysis can support the decision-makers during the planning process allowing them to analyse from various viewpoints the alternative scenarios and to prioritise the different energy measures.

Keywords: energy transition; scenario analysis; GIS-based approach

Introduction

The energy transition regards the decarbonisation of energy systems and entails a significant change in the role of different primary fuels and energy technologies. It is widely recognised that ageing of existing energy systems, climate change, energy security, and depletion of conventional fossil fuels are already modifying traditional patterns and scales of energy supply, distribution, and consumption (Bridge *et al.*, 2013).

In order to support decision-makers upon the energy transition, several tools have been developed. These methods range from the analysis of the current situation of the energy system and the estimation of the present energy demand to the generation of different scenarios at various spatial scales (Nabielek *et al.*, 2018). Scenarios may be particularly interesting tools for analysis in the energy field since they can be used to understand the possible futures of an energy system with and without the implementation of strategic actions and under different conditions (Geneletti, 2012). In this case, the strategic decisions may concern the expansion of specific energy technologies and the combination between various efficiency measures for the building stock. The presented study deals with the development of alternative scenarios for the energy system of Valle d'Aosta region (NW of Italy) and is aimed at suggesting sustainable pathways for its energy transition towards a *Smart Energy Region*. In particular, the strategic actions want to foster the exploitation of Shallow Geothermal Energy (SGE) and the energy refurbishment measures that can increase the energy efficiency in residential buildings.

Shallow geothermal energy is regarded as an environmentally friendly, renewable and sustainable energy (Hähnlein *et al.*, 2013). It represents an attractive alternative to fossil fuels, especially for the heating and cooling of buildings, and it also has competitive advantage in relation to other renewable sources, such as biomass (Zambelli *et al.*, 2018), because of its very limited impact in terms of air pollution. Despite, its diffusion is still marginal; the main reason is the high installation cost of the plant (geothermal heat pump – HP) and the drilling work. The growth of the use of SGE is also limited by complicated and fragmented legislation and by the scarce knowledge on the possible applications of this energy source (Casasso *et al.*, 2017). Hence, it is necessary to increase and spread the awareness of its advantages among policy and decision-makers providing insight and information on how to include SGE source into energy strategies and plans. In addition, in European households the use of energy for heating and domestic hot water (DHW) account for almost 80% of the total final energy consumption (European Commission, n.d.). Therefore, it is impossible to imagine a sustainable energy transition without paying attention to the built environment. The paper presents a spatially-explicit approach to the scenario analysis that, taking advantage of a GIS (Geographic Information System) environment, can support the decision-makers during the planning process allowing them to analyse from various viewpoints the energy scenarios and to localise where is better to address the different energy measures.

Data and method

The construction of scenarios for the energy system of the Valle d'Aosta region was aimed at suggesting sustainable pathways for the energy transition of the case study toward a *Smart Energy Region*. All the features considered in the construction of these scenarios were outputs of previous analyses developed within an EU-funded project under the Interreg Alpine Space programme

(GRETA – Near Surface Geothermal Resources in the Territory of the Alpine Space[1]) and within a PhD thesis (Valentina D'Alonzo – Doctoral School in Civil, Environmental and Mechanical Engineering of the University of Trento).

These previous performed analyses are listed as follows:

- spatial evaluation of the space heating demand of the residential buildings;
- spatial analysis of the financial feasibility for the use of SGE to cover the estimated heating demand;
- exclusion of buildings that fell in areas where environmental interferences and hazards for the installation of SGE systems were detected[2];
- comparison among the objectives of the Regional Energy and Environmental Plan (REEP) of Valle d'Aosta, on one side, and of the Regional Spatial and Landscape Plan (RSLP), on the other side, to highlight conflicts or need to improve the connection with new objectives;
- formulation of more energy-driven objectives.

Starting from the basis of the abovementioned previous analysis, two driving forces were established for the scenario development. They are: 1) using SGE for supplying the space heating demand of residential buildings, replacing as much as possible the fossil fuels; 2) refurbishing part of the residential building stock for decreasing its thermal demand. Different combinations of these two drivers shaped the developed scenarios, which are represented in Figure 1.

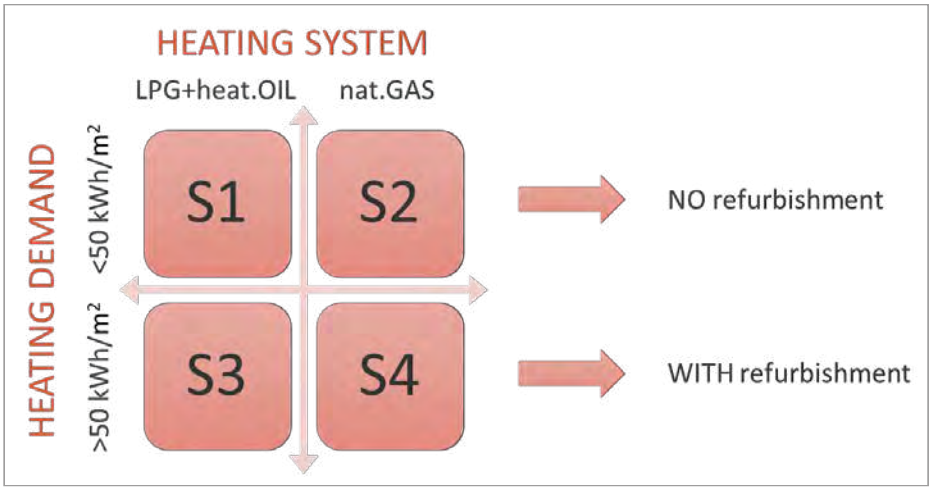

Figure 1: Schema about the developed four scenarios for the case study of Valle d'Aosta region.

In the first two scenarios (S1 and S2), it was imagined that SGE will supply the space heating demand of part of the residential building stock, replacing some fossil fuels but without applying any renovation measures. The buildings considered in these scenarios have a value of estimated space heating demand smaller than 50 kWh/m^2 per year and are located in census tracts where LPG, heating oil and natural gas are used as fuels for the primary heating system.

---

[1] http://www.alpine-space.eu/projects/greta/en/home

[2] http://greta.eurac.edu/maps

For the second section of scenarios (S3 and S4), the residential building stock was supposed to be partially refurbished for decreasing its total thermal demand. At the same time, SGE systems were imagined to be installed in the renovated buildings in place of fossil fuel plants. In this case, the developed scenarios involve the buildings with a value of estimated space heating demand greater than 50 kWh/m^2 per year. It is noteworthy that the buildings considered in these two refurbishment scenarios are equivalent to more than one-quarter of the entire analysed building stock (around 27%).

In the scenarios S2 and S4, the combination of a geothermal HP with PV panels and subsidies was considered because this is the only combination in which SGE would be economically convenient compared to the natural gas option. Furthermore, in these two scenarios the geothermal HP is deemed to be used as the primary heating system and the natural gas boiler as the secondary one, to cover the peaks, as the infrastructure for natural gas would remain active even if the heating system changed.

The scenarios were then analysed and compared through the following indicators:

1. Heated surface of buildings involved [m^2];
2. Greenhouse gas (GHG) emissions saved [tCO_2-eq];
3. Costs of replacement of heating system with HP [M€];
4. Cost of energy renovation of buildings [M€];
5. Electrical consumption for HP utilisation [MWh].

The GHG emissions saved due to the partial replacement of fossil fuels with SGE were calculated by using IPCC emission factors (Joint Research Centre, 2017) for the different energy sources. In particular, the difference was calculated between the emissions of fossil fuel plants (LPG/heating oil, natural gas) and the emissions of the imagined electrical geothermal HP installed to cover the same space heating demand of the buildings.

Mean values for the energy efficiency of the heating systems were taken from the Italian Inter-ministerial Decree 26/06/2015 on the national energy certification of buildings (Ministero dello Sviluppo Economico, 2015) to convert the space heating demand of each building in energy consumption and then in GHG emissions. The total emissions in Valle d'Aosta in 2010 were taken from REEP and considered as the starting point for the calculation of the saved emissions.

The capital and operative costs were estimated in the spatial financial analysis within the GRETA project. Inside the capital costs, the investment for geothermal HP and the drilling works were considered. The capital cost estimation took into account also a 40% increase of the estimated costs for excavation and HP to overcome the high variability of the analysed cases. Inside the operative costs, the cost of electricity and maintenance of the system were instead considered.

The data on energy renovation costs of the selected buildings (in €/m^2) were taken from the outputs of the iNSPiRE project[3]. iNSPiRE was a 4-year EU-funded project whose main objective was to tackle the problem of high energy consumption in the building sector by producing systemic renovation packages that can be applied to residential and tertiary buildings. The renovation packages developed

[3] http://inspirefp7.eu/

by the project aim to reduce the primary energy consumption of a building to lower than 50 kWh/m^2 year.

The increase in electricity consumption due to the installation of geothermal HP was evaluated within the GRETA project, as well as the geothermal HP costs. Also in this case, the total electricity consumption in the Region in 2010 was taken from the Regional Energy and Environmental Plan and considered as the starting point.

Results and discussion

From the scenarios comparison, the third scenario (S3) came out to be the most impactful with respect to all the indicators considered: residential heated surface involved, GHG emissions saved, but also increase of electricity consumption and total costs (energy renovation and/or heating system replacement), see Figure 2. The buildings considered in this scenario are those built between 1946 and 1980, with a value of space heating demand greater than 50 kWh/m^2 per year, where LPG and heating oil are used as primary fuels. With these characteristics, they represent a relevant part of the entire analysed building stock (around 21%). Overall, the first two scenarios, which consider the buildings with lower space heating demand, do not have a significant effect on the status quo. While, the second two scenarios are more impactful, mainly because they involve energy renovation measures for several buildings.

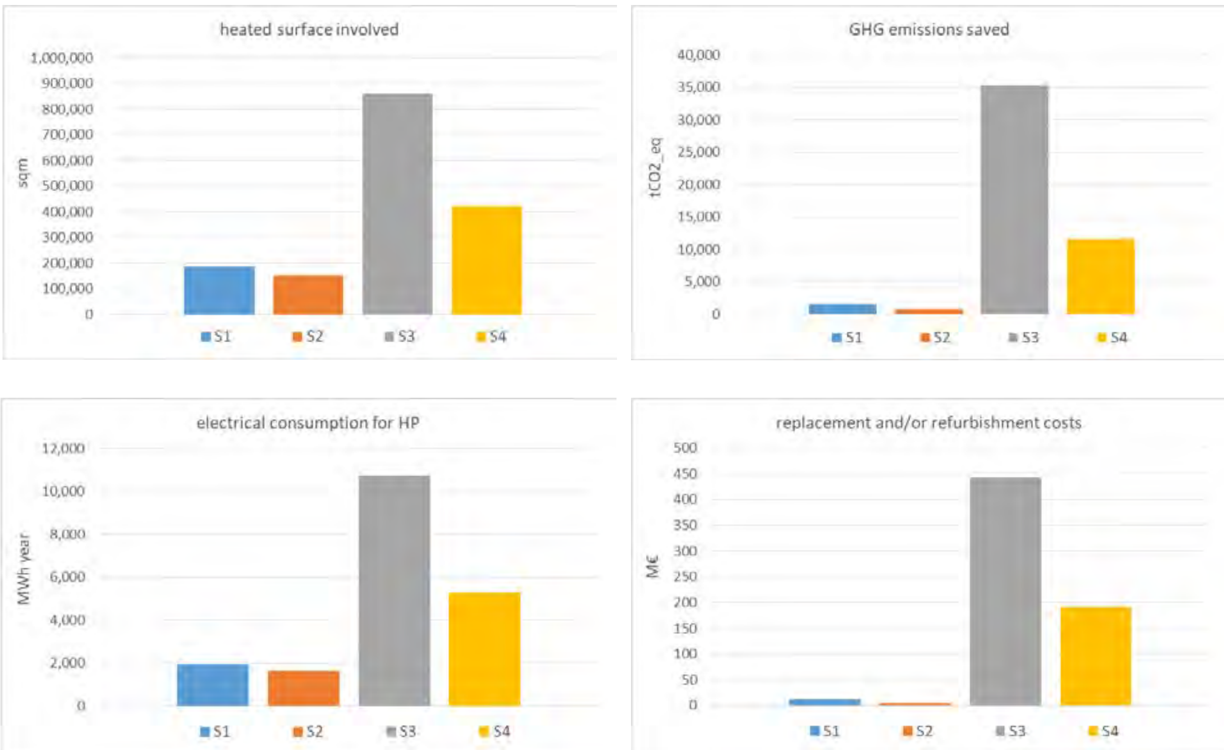

Figure 2: Comparison among the four scenarios developed for the energy system of Valle d'Aosta.

Concerning the saving of GHG emissions and the increase of electricity consumption, one has to bear in mind that the Valle d'Aosta region is already 100% renewable for the electricity production thanks to the hydropower source. Therefore, an increase in the electrical energy use inside the Region would have “negative” effects on the national CO_2 balance but not in the regional context. On the contrary, the Region would use more a local energy source instead of buying fossil fuels from outside (LPG, heating oil and natural gas). In this way, the overall sustainability of Valle d’Aosta would increase in terms of energy self-sufficiency.

Concerning the total required costs and the possible related subsides, the results underlined the importance of the provision of subsidies for the financial convenience of interventions like the installation of geothermal plants and the energy refurbishment of residential buildings. Also the outputs of the financial analysis performed within the GRETA project, underlined that the real discriminant factor on the costs for the installation of geothermal HPs is constituted by the application of subsidies. Thanks to the spatial-based approach adopted, it is also possible to localise the buildings where the ratio between GHG emissions saved and total costs ($kgCO_2$/€) is higher, in order to intervene with policies and/or subsidies for the replacement of heating systems and the energy renovation of buildings earlier on these buildings and thus have the strongest impact on the reduction of GHG emissions.

This method on the scenario development inherited all the limitations of the previous steps (as listed in the previous section), as the starting points are the estimation of the space heating demand of the buildings and the spatial financial feasibility of SGE potential for covering this demand. In addition, this work would represent an example of how this kind of analysis can support the decision-making process when an energy plan/strategy should be updated or developed. The choice of the criteria to be used in the evaluation of scenarios should be better done by the local stakeholders and/or decision-makers. Another aspect worthy to be explored is the analysis of the different measures proposed on the basis of their effectiveness in promoting a sustainable energy transition.

Conclusion

From this study, the energy renovation of the residential building sector is confirmed to represent a great opportunity for reaching the energy saving targets and the reduction of greenhouse gas emissions, in Valle d’Aosta as well as in Italy given the same national building periods. Therefore, the replacement of fossil fuels with RES for the heating systems should be combined with interventions aimed at decreasing the space heating demand of the residential building stock. In this way, we will be able to foster a sustainable energy transition (at regional, national and European scale).

The integration of Shallow Geothermal Energy in the energy planning of cities and regions can, from its side, contribute to the increase of energy efficiency and utilisation of renewable sources in the heating systems, with the consequent reduction of GHG emissions due to thermal energy consumption of the building stock. The development and analysis of scenarios are particularly interesting tools in the energy field since they can be used to understand the possible futures of an energy system with and without the implementation of strategic actions, like the expansion of specific energy technologies and the combination of different efficiency measures for the building stock.

The spatially explicit method presented in this paper can help during the decision-making process allowing to analyse from various viewpoints the different alternatives and also to localise where is better to address the energy measures and thus prioritise the interventions aimed at increasing the energy efficiency and reducing the GHG emissions from energy consumption. Future developments of this method are foreseen to be: a) diversifying the refurbishment interventions for different kind of buildings (dividing them according to relevant criteria) and/or defining an annual renewal rate for both the replacement of heating systems and the energy renovation of buildings; b) performing a cluster analysis for gathering together similar municipalities and then develop different scenarios for each cluster; c) performing a spatial multi-criteria evaluation of the scenarios (Pohekar and Ramachandran, 2004) involving the local stakeholders in the weighting system of the considered variables.

Acknowledgements

This work starts from the outputs of analysis conducted within the GRETA project (2015-2018) and supported by the European Regional Development Found (ERDF) through the Interreg Alpine Space Programme.

References

Bridge, G., Bouzarovski, S., Bradshaw, M., Eyre, N., 2013. Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy 53, 331–340. https://doi.org/10.1016/j.enpol.2012.10.066

Casasso, A., Piga, B., Sethi, R., Prestor, J., Pestotnik, S., Bottig, M., Goetzl, G., Zambelli, P., D'Alonzo, V., Vaccaro, R., Capodaglio, P., Olmedo, M., Baietto, A., Maragna, C., Böttcher, F., Zoesseder, K., 2017. The GRETA project: the contribution of near-surface geothermal energy for the energetic self-sufficiency of Alpine regions. Acque Sotterranee - Italian Journal of Groundwater 6, 23–33. https://doi.org/10.7343/as-2017-265

European Commission, n.d. Heating and cooling - European Commission [WWW Document]. URL https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling

Geneletti, D., 2012. Environmental assessment of spatial plan policies through land use scenarios: A study in a fast-developing town in rural Mozambique. Environmental Impact Assessment Review 32, 1–10. https://doi.org/10.1016/j.eiar.2011.01.015

Hähnlein, S., Bayer, P., Ferguson, G., Blum, P., 2013. Sustainability and policy for the thermal use of shallow geothermal energy. Energy Policy 59, 914–925. https://doi.org/10.1016/j.enpol.2013.04.040

Joint Research Centre, 2017. Covenant of Mayors for Climate and Energy : default emission factors for local emission inventories : version 2017 (EU publications).

Ministero dello Sviluppo Economico, 2015. Decreto Interministeriale 26/06/2015 - Adeguamento linee guida nazionali per la certificazione energetica degli edifici.

Nabielek, P., Dumke, H., Weninger, K., 2018. Balanced renewable energy scenarios: a method for making spatial decisions despite insufficient data, illustrated by a case study of the Vorderland-

Feldkirch Region, Vorarlberg, Austria. Energ Sustain Soc 8, 5. https://doi.org/10.1186/s13705-017-0144-x

Pohekar, S.D., Ramachandran, M., 2004. Application of multi-criteria decision making to sustainable energy planning—A review. Renewable and Sustainable Energy Reviews 8, 365–381. https://doi.org/10.1016/j.rser.2003.12.007

Zambelli, P., D'Alonzo, V., Vaccaro, R., Garegnani, G., 2018. A SDSS to Integrate Ground Source Heat Pump into Regional Energy Strategies, in: 9th International Congress on Environmental Modelling and Software. Presented at the 9th International Congress on Environmental Modelling and Software, Mazdak Arabi, Olaf David, Jack Carlson, Daniel P. Ames, Fort Collins, USA.