AERIAL LIDAR AND INFRARED THERMOGRAPHY FOR URBAN-SCALE ENERGY ASSESSMENT AND PLANNING

AIT Series

Trends in earth observation

Volume 3

Earth Observation: current challenges and opportunities for environmental monitoring

Edited by

Associazione Italiana di Telerilevamento (AIT)

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Preface

Since its foundation 1986, the Italian Society of Remote Sensing (Associazione Italiana di Telerilevamento – AIT) has been engaged in the dissemination of knowledge of remote sensing and Earth Observation (EO), with a particular effort in fostering scientific and operational consciousness about their exploitation.

AIT is specifically committed to:

(i) create a network connecting people from Research, Academia, hi-tech Companies, Administrative Institutions and Professionals involved in territory management and involved, or interested, in the development of Earth Observation methods, techniques and applications;

(ii) promote and coordinate initiatives to foster the exploitation and the technology transfer of remote sensing technologies, like the organization of congresses, conferences, workshops and thematic Summer/Winter schools;

(iii) promote the exchange of knowledge and cooperation among its members to "shorten" the technology transfer chain;

(iv) serve as the Italian national representative and reference player on matters pertaining to remote sensing and Earth observation-related issues for institutions, agencies, and companies, at the national and international levels;

(v) maintain an ongoing observation of technological and scientific advances, with particular attention to datasets, products and services from open, or commercial archives, to ensure a conscious and proper exploitation by users;

(vi) draft guidelines for the definition of possible standards about data quality, data processing, validation methods and accuracy metrics related to EO.

As AIT President for 2023-26, I specifically encouraged the Executive Board to focus on points (iv-vi), whose inner meaning have to be better specified.

Concerning point (iv), the 2023 AIT Congress, from which the contributions of this volume were derived, made evident the high expectations that Institutional players have in respect of the EO scientific community, especially related to the ongoing post-pandemic Italian National Plan for Recovery and Resilience (PNRR). The newly programmed Italian IRIDE Program for EO, supported by ASI and ESA, and the various territorial needs discussed along the congress sessions, definitely highlighted the strategic role of EO in this framework.

Discussions at the 2023 AIT Congress also highlighted we are experiencing a too-fast technology advancement, paradoxically slowing down the technology transfer. In fact, low-cost and user-friendly tools are continuously made available, providing users with the illusion of operational autonomy despite their domain knowledge is low or non-existent. This situation makes it extremely difficult to recognize applications based on a solid and proved EO-, or more generally, Geomatics-related knowledge, thus introducing a high degree of unreliability

The EO and Geomatics scientific communities may have reacted too slowly and disjointedly to this phenomenon and now need to regain a new role in supporting a proper (reliable) technology transfer. I retain that the main reason about this failure relays on the new and reverted relationship linking the Applied Sciences with the technological market. Today, more than ever, technology often anticipates applied sciences requirements, proposing solutions to problems that have yet to be solved. The feeling is that scientists and scholars are currently being asked to go back along the supply chains to obtain proper technical specifications needed to consciously experience new devices (or products and services) and test them under the right conditions. In most of the cases, they are also called to find a suitable and valuable application that the newly proposed low-cost technology can be useful for.

A further, recent new challenge is coming from the unstoppable introduction of Artificial Intelligence in our life, including EO and Geomatic processes. The 2023 AIT Congress proved that the EO context is one of the mostly involved sectors from this point of view. But, is this really healthy for Science? Is this safe for a sustainable development? AIT opinion is that scientific societies and Academia are called to slow down this trend where an immediate exploitation of new continued technological advances has to come. A new paradigm has to be introduced where the ongoing "continuous" technology transfer has to move to a "discrete" one. This means that, at the application level, the technological (and algorithmic) level have to be fixed at a certain point and reconsidered/updated after a time step consistent with the time of: (i) engineering of processes; (ii) definition of controlled (by reference subjects) procedures for both data processing and validation of results; (iii) validation of global data/services at the local level. This would permit a proper ingestion and exploitation of the technological advances that we are ordinarily stimulated about, and a proper development of users' consciousness needed to prepare a more effective advance in the next evolution step. AIT, under my leadership, supports a SLOW, but conscious, SCIENCE.

In this framework, AIT supports open and wide-ranging actions involving multiple players and scientific associations at national and international levels. Among these actions, one deals with the education/formation in EO with a special focus on the importance of consciousness of data and methods. In 2020, AIT has strongly supported the launch of the Italian National PhD Course in Earth Observation specifically designed with the main goal of training professional figures with transversal and integrated skills of Earth Observation and Geomatics, and specific application, administrative and legal skills, able to effectively support the wider exploitation and use of the EO programs and related services.

AIT, together with Stati Generali dell'Innovazione - SGI and AM/FM GIS, is supporting the Italian National Copernicus User Forum in collecting Geomatics-related needs from users and providing proper guidelines for conscious exploitation of the available technology and data. The goal is to build a unique solid entity having the scientific strength and the political weight of acting like the accredited interlocutor when a Geomatics-related need arises from institutions (but not only). it is AIT conviction that this would permit an immediate and unambiguous recognition from users of their reference speaker, when a geospatial information-related problem has to be faced. Additionally, this would trigger a virtuous process for even defining standards for data acquisition and processing able to recover a leading role for the Geomatics and EO community in the framework of a conscious and sustainable technology transfer process.

To achieve the above-mentioned goals, AIT operates through the following actions:

(i) it is presently a partner of the Italian National Copernicus User Forum;

(i) it is the reference scientific society of the European Journal of Remote Sensing, an open-access scholarly journal published by Taylor & Francis;

(ii) it is the reference scientific society of the European Journal of Remote Sensing, an open-access scholarly journal published by Taylor & Francis;

(iii) it is one of the 4 confederated scientific societies of ASITA, the Italian Confederation of the Scientific Associations for Territorial and Environmental Information, where EO integrates with the other branches of Geomatics at Italian national level;

(iv) since 2016 AIT started to propose and give its International thematic summer/winter schools mainly addressed to support the conscious exploitation of the Copernicus and ASI (Italian Space Agency) data, products and services;

(v) AIT organizes its Congress every two years. Selected and blinded reviewed contributions from the Congress are gathered and published in a Scopus and WoS indexed book Series named "Trends in Earth Observations (TEO)". These volumes are intended to present a snapshot of the state-of-the-art in several application fields and advice about potentialities and limits from the ongoing trends of EO technology transfer.

AIT President (2023-2026)
Enrico Borgogno Mondino

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AERIAL LIDAR AND INFRARED THERMOGRAPHY FOR URBAN-SCALE ENERGY ASSESSMENT AND PLANNING

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ABSTRACT:

Recent policies at the national and international levels showed the need for effective tools supporting policymaking. This study – primarily based on energy classification – uses thermographic pictures and GIS technology to define the energy needs of a district in Turin, Italy. Potential savings – in terms of primary energy consumption and carbon dioxide emissions – are assessed based on two retrofit scenarios and alternative energy supply options. A further element, i.e. the photovoltaic potential, is introduced to assess – starting from classified LiDAR data – the possibility to introduce self-production forms for reducing even more the impacts of the energy sector. The results show the potential for further studies based on 3D modelling, oriented towards the implementation of a thematic layer for the Urban Digital Twin.

1. INTRODUCTION

1.1 Framing of the study

With the ongoing urbanization trend, there is a pressing need for policies to reduce energy demand and deriving environmental problems. In this context, the fit for 55 package – including the revision of the Renewable Energy Directive, Energy Efficiency Directive and Energy Performance of Buildings Directive – targets an 80-95% reduction of GHG emissions (compared to 1990 levels) by 2050.

Policymakers require effective tools for supporting their decisions, e.g. mapping the current status of energy performance according to the EPBD. Geographic Information System is a powerful tool to integrate and synthesize multiple datasets – be they tables, vectors or imagery. In the energy sector, GIS can be used to draft Urban Building Energy Models with a low appeal to archetypes thanks to the continuity granted by geographic data. Aerial thermography can be used to define a consumption model based on the thermal dispersion of buildings. While this method is widely validated on a building scale (Martin et al., 2022), its potential on district and city scales still has to be unlocked. Moreover, it is possible to georeference the information contained in Energy Performance Certificates – required since 2002 before any intervention – to improve the calculation model by adding further parameters.

1.2 Workflow

The work is structured in two main components: a consumption and photovoltaic productivity analyses are carried out contextually, thus exploring the possibility to create a Renewable Energy Community in the area of interest.

The demand estimation is conducted by estimating the thermal performance of the envelope from thermographic pictures and correlating the energy performance class observed in a set of Energy Performance Certificates issued for the area of analysis. Potential productivity from photovoltaic panels – intended to understand the share of renewable energy to meet the total demand – is estimated with a GIS-based viewshed algorithm from the Digital Surface Model, realised starting from a LiDAR point cloud.

Two renovation scenarios are then explored, considering the potential benefits from renovating the building stock and partially electrifying the energy systems for heating and cooling.

1.3 Study area

The study area is located in the Northern part of Turin, in the *Barriera di Milano* district. It is bounded by relevant mobility infrastructures – a former railway in the North and high-capacity avenues on the other three sides – with further two principal roads crossing it and characterised by problems affecting both its physical and social structures. Two main clusters were highlighted for this research, with a former industrial plant in the North and a functionally mixed area in the South.

The study area is heterogeneous, with an inner dense residential fabric and industrial buildings – partially reconverted for commercial purposes – on the borders. Indeed, the district grew after the post-war economic boom, with industries along the commercial axes and residential buildings to meet the deriving housing demand. The quick and serial realisation led to poor-quality constructions, resulting now in problems such as inadequate energy performance. From this it arose the need for a wide-scale energy classification, supporting future policies for extensive energy renovations and assessing the results of refurbishments which already happened. Further details are provided in (Anselmo et al., 2023).

2. CONSUMPTION ANALYSIS

2.1 Thermographic acquisition

The evaluation of the thermal energy demand started from thermographic images acquired on 9/1/2022 with a FLIR A8581 MWIR HD camera – registering wavelengths of 3-5 µm with

* Corresponding author

±1°C accuracy. They were orthorectified to remove distortions, producing thermal orthoimages. Despite the possibility to see the roofs only due to the nadiral perspective, the 1.3 MP resolution ensures the recognition of disturbing elements – like chimneys and dormers – affecting the results. However, the diurnal acquisition – around midday – led to shading problems, with sunny pitches returning considerably higher values compared to the shadowed ones. Due to the exploratory nature of this research, it was not possible to have a dedicated acquisition, resorting instead to existing datasets with limited availability.
The thermographic pictures – provided orthorectified but not geolocalised – were first georeferenced with ArcGIS Pro. After a first adaptation through scaling and rotation, the georeferencing tool requires the user to input Ground Control Points by comparing the image to be georeferenced with a georeferenced one, requiring a higher resolution not to reduce the accuracy. In this case, a precision orthophoto – 5 cm accurate – realised in the TerraItaly™ Metro HD project for the SDG11 Lab was used. On average, the resulting forward error was 0.941, while the inverse was 1.412. The five images – one stand-alone and the others grouped in couples – cover an area of approximately 0.35 km^2.

2.2 Definition of consumptions

Thermographic pictures return the outer temperature of buildings. Assuming the internal temperature as constant – considering that the flight was carried out during the heating season, with the temperature set by Presidential Decree 16 April 2013 n. 74 to be 20°C – and the roofs to be homogeneous – realised with the same material, thus resulting in similar thermal storage and emissivity – the outer surface temperature can be used to quantify the thermal dispersion and therefore the energy class. For this step, Energy Performance Certificates – regulated in Italy by the Legislative Decree 192/2005 – were gathered, defining the distribution of buildings in the classes and the reference Global Energy Performance Index (as the median of the values registered in the EPCs for that class). Results are summarised in Table 1, with differences emerging in the intervals between the values. They are minimum for central classes, increasing towards lower classes: class G requires approximately 100 kWh/m^2 more than class F, while only 15 kWh/m^2 divide classes C and E. As for the count, class F is the one with the most units, with less performing classes outnumbering the upper ones.

Energy class	Count [-]	Share [%]	Reference GEPI [kWh/m^2]
B	3	4.65	98.06
C	3	4.65	118.95
D	11	16.74	123.15
E	17	25.58	130.49
F	20	30.23	176.24
G	12	18.14	276.22
Average	11	16.61	153.85

Table 1 – Energy classes and reference GEPI

The reference GEPI was multiplied by the gross floor surface – defined as the footprint multiplied by the number of floors – and divided by the conversion factor of the natural gas to compute the thermal energy demand. On the other hand, the electricity demand was esteemed as 1113 kWh/inhabitant, based on ISTAT data. The total energy demand is shown in Figure 1.

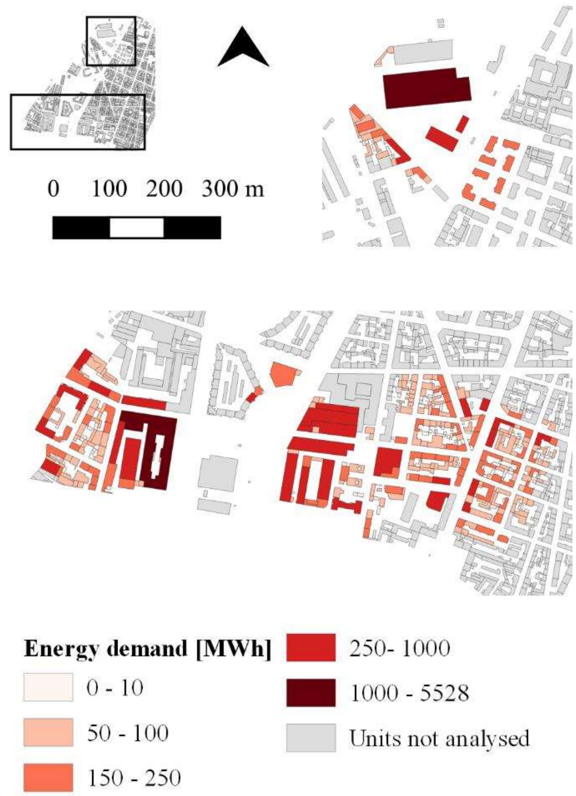

Figure 1. Total energy demand

The former industrial plant in the North is composed of the most energy-intensive units, due to low performance and big surfaces to be heated. The westernmost area – partially renovated – has some of the most performing buildings, while there is high heterogeneity in the Eastern cluster. As for class characteristics, the gross floor surface increases constantly from B to F, while class G buildings are smaller compared to the previous class. This partially mitigates their impact, resulting from high consumption. The total thermal energy demand amount to 42 GWh/year, equal to 155 kWh/m^2, which makes the average building classifiable in class E. As for electricity demand, 37% of the buildings have residential units, with a total need of 3 GWh/year (9% of the total energy demand), corresponding to 19460 kWh/year per building.

3. LIDAR POINT CLOUDS

In this work, a DSM produced by Compagnia Generale Ripreseaeree was used, but it is relevant to mention how LiDAR point clouds are processed to produce a DSM.

3.1 LiDAR classification

Light Detection and Ranging (LiDAR) is one of the principal technologies for large-scale 3D modelling. It generates a brief laser pulse and registers the reflection (Croneborg et al., 2020), thus creating a cloud of points with known positions.
There are two main methods for LiDAR data classification: feature extraction and machine learning. The former segments the dataset based on spatial and radiometric information, while the latter has seen recent evolutions in the field of computer vision and deep learning. PointNet is a deep neural network processing the 3D point cloud without conversion, unordered. It uses transformation matrices and the max pooling method to classify the point cloud elements, abstracting the features of the original point cloud through subsequent iterations (Zhongyang et

al., 2018). The segmented point cloud can be used to return different products, according to the required application.

3.2 DEMs production

Classified point clouds can be used to produce a 2.5D Digital Surface Model (DSM), which describes on a bi-dimensional raster map the surface of objects from the real world. For the rasterisation, two types of processes can be carried out. Among the semi-automated solutions, CloudCompare requires the user to input the cell size of the regular grid to be returned, the vertical direction (Z) and the interpolation method to be used to fill up the spaces with no information. On the other hand, the module DSM in OPALS (Orientation and Processing of Airborne Laser Scanning data) – developed by TU Wien – is fully automated. It is based on the iteration of sub-sampling grids until either the neighbour count or the maximum search radius is reached, followed by a moving planes interpolation.
While the DSM takes into account the whole point cloud, pre-processing is required to derive other Digital Elevation Models (DEMs), such as the Digital Terrain Model. In particular, in this case, a filtering phase is required to select only the ground points. The appropriate DEM is to be selected according to the application and the required accuracy, so as to minimise elaboration times.

4. PHOTOVOLTAIC POTENTIAL

Solar energy is the most suitable Renewable Energy Source (RES) for being installed in the built environment, due to the possibility to integrate solar panels on the roofs. This reduces both the investment costs – not requiring the construction of further structures – and the visual impact of this technology. The photovoltaic potential was calculated based on the solar radiation striking the roofs, according to the Suri equation (1):

$$PV_{potential} = \text{Solar energy} * PI * \eta * \text{surface [kWh/year]} \quad (1)$$

Where Performance Index PI – quantifying the efficiency of the system – was assumed to be 75%, the conversion efficiency η depends on the technology to be installed and the surface is assumed to be 40% of the unit footprint – a value which includes correction factors for inclination and presence of obstacles.

4.1 Solar radiation evaluation

Starting from the DSM elaborated from LiDAR data, it was possible to evaluate the solar energy using the “Area solar radiation” tool of ArcGIS Pro (ESRI). Parameters were set according to the need to minimise the elaboration time while keeping the calculation accurate. The default sky size – 200 – was kept, while the hour interval was increased to 1 hour, analysing the radiation with a “whole year” time configuration. Thus, by default, the day interval is set to 14 days, using 2022 as the reference year. The “slope and aspect input type” was shifted to the option which uses the input DSM for calculating the exposition, calculation directions were reduced from 32 to 16.
The crucial aspects were the radiation parameters. As “diffuse model type” it was chosen the “standard overcast sky”, with which the diffuse radiation flux varies based on the zenith angle. Diffuse proportion and transmissivity values – summarised in Table 2– make the study site-specific by including weather data differentiated depending on the season. Diffuse proportion is returned by PVGIS – an online tool by the European Commission – while for the latter further calculations are required, crossing data from the same source with fixed parameters as the LINKE turbidity factor and the solar constant.

Season	Diffuse proportion	Transmissivity
Winter	0.38	0.56
Summer	0.38	0.76
Spring/autumn	0.42	0.67

Table 2. Diffuse proportion and transmissivity parameters

The tool processes on average around 0.7 km^2/h, thus requiring nearly two hours to process the area of interest for each iteration. For this reason, seasonal averages were used, aggregating four months for each.
The “Area solar radiation” tool returns monthly values, making therefore possible the comparison of different months. By checking the two months for which the radiation is minimal – December – and maximal – August – it is possible to observe a relevant difference apart from the one in the energy values, that is the solar height. In summer the sun rays strike not only the roofs but also the roads and open areas. On the contrary, in winter months the roofs are the only surfaces with relevant production values, thus justifying their selection for the installation of photovoltaic modules. Values were then aggregated yearly, as shown in Figure 2.

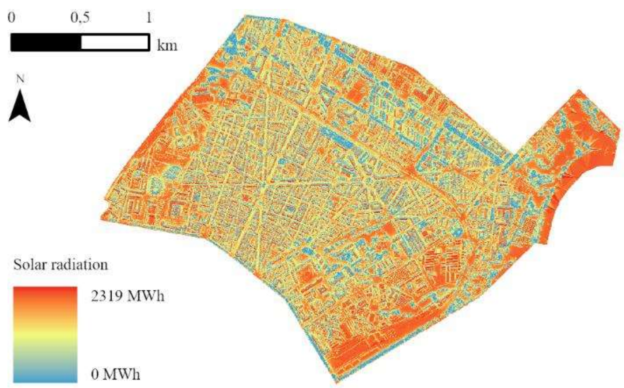

Figure 2. Yearly solar radiation

4.2 Producibility of photovoltaic panels

Once having calculated the solar radiation, it is necessary to refer production values to the volumetric units. This can be done in a few steps, converting each cell of the raster output to points and joining the values of the closest point to the centre of the volumetric unit. By choosing this procedure instead of calculating zonal statistics based on the volumetric units, the portion with the highest radiation is taken, not considering the potential errors on the roof edges.
After that each volumetric unit is assigned a reference radiation value, it is possible to compute the potential production. Conversion efficiency, according to (Green et al., 2022), was esteemed to be 24.2% for crystalline cells, 18.4% for polycrystalline and 11% for thin film. When installing the second, approximately 8.8 GWh can be produced yearly, with a great variability for each volumetric unity, mostly based on the exploitable surface. Indeed, all buildings producing more than 120 MWh/year have 1200 m^2 of available roof surface or more. Compared to polycrystalline, monocrystalline modules have higher productivity, thus being able to produce the same amount of energy with a lower surface or produce more with the same surface. On the other hand, thin-film modules produce less but are also cheaper.
Comparing the potential polycrystalline production to the esteemed consumptions – assumed to be 1000 kWh/person/year, it emerges that around half of the volumetric units could produce by itself the electricity needs. Moreover, 15% of the units can

produce twice their demand, with the ratio between total production and consumption being 83.2%. Therefore, collaboration forms can be foreseen, dividing benefits and burdens within the community.

5. RENOVATION SCENARIOS

The previous results were integrated to elaborate two alternative retrofit scenarios. The first is the optimum, foreseeing a reclassification of all buildings in class B, and the second targets an improvement by two classes for every unit. They were compared by assessing four alternative energy supply options, that are District Heating (DH), natural gas (G), a mix of district eating and natural gas (M) and heating pumps – partially covering the demand through photovoltaic production – (HP+PV). In the first three scenarios, electricity is taken from the grid.

5.1 Energy saving

The first assessment concerned the savings in terms of primary energy. Figure 3 shows the current state – with all buildings heated through natural gas boilers – and the comparison of the two scenarios with different energy supply options.

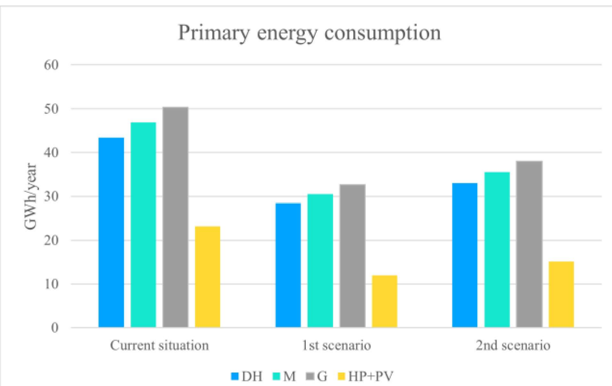

Figure 3. Primary energy Consumption

The least savings are achieved by renovating the buildings without changing the systems servicing them, while the installation of photovoltaic panels and heating pumps would lead to a doubling of the savings. District heating – likely to be introduced in the district in the medium term according to the project North East – is the most effective energy supply option which does not foresee electrification for maximising the savings, reducing consumption 15% more than with natural gas boilers.

The optimum scenario would grant savings of at least 35%, with additional 4 GWh of primary energy saved yearly in the case of district heating implementation. Self-production and the use of heating pumps would cut the consumption by ¾, that are 48 GWh.

In the second scenario – the most likely thanks to lower investments needed – 26% of the volumetric units would fall into class B, decreasing primary energy consumption by 25% to 70%, depending on the energy supply. This makes it suitable to use the second scenario as an intermediate step towards a full renovation. Moving from this scenario to the optimum without changing the energy supply would result in savings from 14% to 21%. However, an even wider difference – 25% equal to 9.6 GWh/year – can be observed between the second configuration with natural gas boilers and the first with district heating.

5.2 Decarbonisation potential

An energy retrofit would also help the Municipality to achieve climate neutrality, considering that in Turin the residential sector causes 37.2% of the total carbon dioxide emissions.

Figure 4 quantifies the savings in terms of tonnes of equivalent CO_2 in the two scenarios, with the general outcomes being similar to the takeaways of the primary energy analysis. The HP+PV solution in the two scenarios would grant – respectively – savings equal to 59.53% and 56.59%.

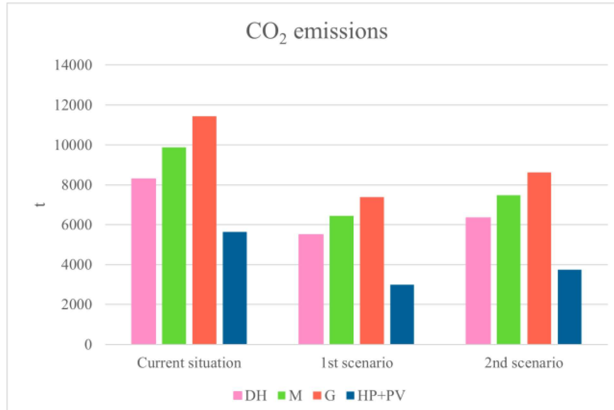

Figure 4. CO_2 emissions

At least 2829 tonnes of CO_2 could be saved – improving the building stock by two classes and keeping natural gas boilers –, with savings reaching 8460 t_{CO_2} in the best option.

Compared to the previous analysis, with this parameter the upgrade from the second to the first scenario is more convenient. A transition towards district heating would result in savings 10% higher, 6% in case of a mixed scenario. On the other hand, savings are 3% lower considering heating pumps.

6. CONCLUSIONS AND FURTHER DEVELOPMENTS

This article focused on a method to perform an energy assessment – for both production and consumption – through the tools of remote sensing. Two retrofitting scenarios were compared in terms of primary energy saving and prevented emissions, taking into account alternative energy vectors. The first scenario grants the most benefits, but the second requires a lower investment, being therefore a better trade-off between costs and benefits. Investments would be needed also for the electrification scenario, thus requiring additional calculations on the payback period, based on the relevant savings which would derive.

This method proved to be simple and easy to use so that it can be attractive for policymakers. On the other hand, there were problems with data availability and simplification. A first improvement would derive from the acquisition of a better thermographic dataset – granting oblique pictures for full 3D reconstruction and the absence of solar radiation flawing the results – which can push the automation of the processing. Another key aspect is the definition of the necessary technologies for increasing energy efficiency, quantifying the necessary investments too. Moreover, also the costs relative to the installation phase should be taken into account.

Finally, this could be a first supporting tool towards the identification of areas suitable for the creation of Renewable Energy Communities, based on their potential and limitations – in terms of dimensioning and potential production. To do so, the principal aspect to take into account is correlation, defined as the time shift between the peaks of energy production and consumption, both during the day and the seasons. The two scenarios can be used for the definition of a roadmap towards the creation of energy communities, reducing the energy needs for taking a step forward in the direction of self-production.

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REFERENCES

Anselmo, S., Ferrara, M., Corgnati, S.P., & Boccardo, P. (2023). Aerial urban observation to enhance energy assessment and planning towards climate-neutrality: A pilot application to the city of Turin. In *Sustainable Cities and Society*, 99, 104938. https://doi.org/10.1016/j.scs.2023.104938

Croneborg, L., Saito, K., Matera, M., McKeown, D., & van Aardt, J. (2020). *Digital Elevation Models*. World Bank, Washington, DC. https://doi.org/10.1596/34445

Green, M. A., Dunlop, E. D., Hohl-Ebinger, J., Yoshita, M., Kopidakis, N., & Hao, X., 2022. Solar cell efficiency tables (version 59). In *Progress in Photovoltaics: Research and Applications*, 30(1), 3–12. https://doi.org/10.1002/pip.3506

Martin, M., Chong, A., Biljecki, F., & Miller, C., 2022). Infrared thermography in the built environment: A multi-scale review. In *Renewable and Sustainable Energy Reviews*, 165, 112540. https://doi.org/10.1016/j.rser.2022.112540

Zhongyang, Z., Yinglei, C., Xiaosong, S., Xianxiang, Q., & Li, S. (2018). Classification of LiDAR Point Cloud based on Multiscale Features and PointNet. In *2018 Eighth International Conference on Image Processing Theory, Tools and Applications (IPTA)*, 1–7. https://doi.org/10.1109/IPTA.2018.8608120