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The carbon footprint of the historic centre of the Municipality of Trevignano Romano - Lazio Region, Italy

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Abstract
Operations to quantify the CO_2eq emissions of a given territory encounter critical issues that make the matter more complex because they are rooted in political/economic/social options carried out over time and in other locations; options that "come from elsewhere and far in time" and therefore make partial the technical solutions that are proposed today. Each intervention must therefore be "contextualized in space and time" otherwise the technical initiative in progress, not well understood, can create the misunderstanding of being proposed again, in other territorial contexts with deep and different connotations, with consequent results that are only partially positive. Moreover, each intervention, for an obvious economy of scale, must be correlated at the same time with similar ones and, in any case, all of them must be placed coherently within an economy that today goes towards industry 4.0. through digitalization. This case study precisely because it is placed "today" and "within" a specific context possesses such specificities that it allows (even foreign entrepreneurs, as well as national) to operate adequately. Following the analysis of the most suitable tools for measuring environmental impacts – on the building and urban scale – the carbon footprint procedure has been defined, the working methodology, the technical operations carried out and the calculation methods for quantifying the CO_2eq emissions produced by the energy consumption of buildings and transport are illustrated through the indicators for the case study under examination, analysed at 360°. Finally, the proposal for the overall reduction of the calculated carbon footprint is illustrated and concludes with the results achieved and their possible further developments.
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Keywords: Carbon footprint; Building retrofit; Digitalization; Industry 4.0; Sustainable urban development; Transport.

1. Preliminary remarks
The operations (which at first glance appear simple, not to say obvious) of quantifying the CO_2eq emissions of a given area taken as a sample, make the issue of environmental sustainability objectively more complex and very articulated, since the criticalities that are found are rooted in political/economic/social options that have been carried out over time and in other locations. Roots that have already given rise to numerous

and articulated criticalities in terms of economic, environmental, social (and therefore also health) damage that the research institutes and the media constantly denounce and testify to with verified, documented and incontrovertible data [1]. Critical issues that, therefore, since they "come from elsewhere and from afar in time", can only underline as partial the technical solutions that we try to propose today in the (false) conviction of solving the problems they themselves, and at the time, determined. The solution lies essentially in the fact that any (albeit commendable) initiative of intervention must be "contextualized in space and time" (where "space" means the specific physical places on which to intervene and "time" means a continuous comparison between the conditions that are found "today" compared to those of the "past"). Moreover, since this contribution is hosted in an international publication (International Journal of Energy and Environment), the above mentioned contextualization must necessarily be punctuated, expanded and carried out in very specific terms in order to better understand (by readers and economic operators, certainly not all Italian) the different connotations that this theme assumes "in Italy" (correlating them to the model of economic/social/environmental development that is registered there), but above all "today" in function of new laws, regulations and procedures in course of implementation, of the passage of the building sector towards "industry 4.0" and new needs expressed by civil society. Finally, having to intervene only on a building and only for aspects related to sustainability, it is clearly reductive – if not short-sighted when it would be far preferable – even for an economy of scale, to work on an urban sector and extend the intervention to other operations of maintenance, of re-functionalisation of distribution, of compliance (think for example, of the seismic one) in fact, the article 7 of the "growth decree" [2] provides tax relief for the energy requalification (in one of the energy classes "A" or "B") and imposes the reconstruction also in an anti-seismic key. Therefore, there are three, very specific and different, necessary "contextualizations" (or, if preferred, recommendations) to be clearly underlined in order to make it understood – even technically – what we intend to do, how, in what way and, above all, what results – realistically – can be expected. Without this (right) premise, a simple technical illustration of a research, and/or an ongoing initiative, not only is not well understood but can create the misunderstanding of being able to be proposed again, with consequent results only partially positive, "today" and "in other territorial contexts" with deep and different connotations. Of the three contextualizations, two can be anticipated here in the introduction, while the third – which relates specifically to the subject matter of this publication – will be explained in the paragraphs dedicated to the introduction and, then, more specifically from a technical point of view, in that of the methodology used. Proceeding in order (but not in terms of importance and/or priority) with respect to the above two first contextualisations/recommendations:
- Operate today in the economic and regulatory context adopted in Italy that is moving towards "industry 4.0" regulated by the new Procurement Code [3] by sector-specific regulations and related measures to obtain incentives and tax deductions; characterized by digitization and off-site production.
- Moving from an artisan logic, even if evolved, to a para-industrial one, since it would be desirable (and more significant results and economies of scale would be obtained) to intervene not on single buildings but on urban fabrics and to take the opportunity of energy requalification to bring buildings up to standard also on the static and functional profile to satisfy the new needs of society: ageing, migrants, singles [4].
- Finally, by interpreting the house no longer as a good but as a service – using home automation for this purpose – fundamental for the users of the spaces, based on a series of sensors, able to carry out energy-environmental, acoustic and CO_2eq emissions monitoring in the environments; also used to report burglaries to safety and to control the health conditions of people.

2. Introduction
Taking up the recommendations (this is the third one), it was said that from a long time ago; in fact, there was a distorted urban development which, built in the absence (or in contempt) of specific regulations, obliges (purely by way of example) the use of a private transport, having to renounce – forcibly – the public ones (preferably by rail); from elsewhere comes a scarce development of Local Public Transport (LPT). Always from elsewhere, the market that imposes the purchase of cars. Within this context, without, unfortunately, being able to influence it, there are numerous researches (such as the one we are trying to illustrate briefly here) that, through more and more advanced technologies, try to propose – even innovative – ways of intervention and bringing buildings up to standard: the systems, the envelope, the home automation, etc., using the regulations (some of them very recent and in the testing phase) that make buildings almost zero consumption [5]. In short, it is the same commitment that is found in international research projects such as Horizon 2020, unlike the intentions of the various COPs (Conference of the Parties), which propose objectives (politically, but also materially) that are difficult to achieve; the same

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is also true at local level, such as the experience illustrated here, in which the same commitment is found (Sustainable Mobility Plans, Action Plans, etc.), but often "not determined within" their specific context and therefore – as mentioned – with objective results that are only partial. The term "within" is insisted upon to justify that any proposal cannot, even if pursued with honesty of purpose and with adequate competence, produce if not partial results, well below the level that the problem would require, if not "contextualized" with a whole series of other aspects (possibly at 360°) with the necessary punctuality.

The case study presented here, precisely because it is well placed "today" and "within" a share of the Lazio territory (the Municipality of Trevignano Romano) has its own specificity: it has been studied and is being tested) in a well-defined context and especially managed by a single administration. The case study refers to the survey (2016-2017) – jointly elaborated by the Inter-Departmental Center CITERA of the Sapienza University of Rome and the Municipality – for the elaboration of the Sustainable Energy and Climate Action Plan (SECAP).

A well defined space and a single governance allow to amplify and generalize the expected results, and even if currently for the benefit of only one specific user, at the same time they are proposed as reliable tests for further experiments to be exported to another scale and different contexts. This means establishing – in the near future – synergies also with adjacent Municipalities, to implement positive exchanges at a larger scale: in short, to try to change concretely where possible and with adequate timing that context "today" unfortunately characterized by options that "come from elsewhere and from afar".

To conclude the introduction, before going into the specifics of the subject and illustrating in detail the technical operations carried out, a brief, very brief mention that then refers to the next text, to anticipate and outline the work programme.

First of all, a proper reference to the current general environmental conditions (which, however, are not always as we believe "best" in small peri-urban centres, to continue with a brief mention of the most suitable tools for measuring impacts on both the building and urban scales today; each with its own set of descriptive and/or performance indicators and calculation procedures. In the international context, on the building scale, for example: GB tool, LEED, LENSE, SB100, SB Method, Total Quality Assessment, BREEAM, CASBEE, ECO-BAU Minergie, HQE and also, the very recent EU Level(s), the first common framework of indicators and metrics for measuring the sustainability performance of buildings, residential and tertiary, new or subject to "major renovation"; in the Italian context instead: LEED Italy, CasaClima, ITACA.

On the urban scale, however, in the international context: EMAS2, LEED NB, PLACE3S, ZED Standards, Agencia Local Ecologia Urbana Barcelona, BREEAM Communities. In the Italian context ECOCITY, ITACA urbano, Torino Olimpica.

In addition, tools such as the ISEW (Index of Sustainable Economic Welfare) have also been developed to integrate the information contained in GDP; the HDI (Human Development Index) which uses indicators such as life expectancy and education [6]. Other methodologies on an urban scale refer to the ecological footprint [7] and the carbon footprint for the evaluation of environmental performance related to CO_2eq emissions associated with activities in the territories analyzed [8]. This method highlights how metabolic efficiency and CO_2eq emissions are very dependent on the characteristics of the place where the territory/city is located (climate, transport system, accessibility, renewable energy resources, morphology, population density, characterizing economic activities, waste management).

In this study, the carbon footprint procedure was chosen. It will therefore also be necessary to define "today" the term "carbon footprint", which is also mentioned in the title and among the key words.

3. Carbon footprint

The carbon footprint is an aggregate and synthetic indicator that relates the lifestyles of individuals or populations with the amount of greenhouse gas emitted (generally expressed in tons of CO_2 equivalent). It represents about 50% of the entire ecological footprint.

It is a conceptually simple indicator with a high communicative content as it represents this relationship with a parameter that is easy to understand: the area (expressed in hectares per capita) of natural surface (forest) necessary to absorb the carbon dioxide emissions generated by human activities resulting from the use of fossil fuels. According to the indications of the Kyoto Protocol, the greenhouse gases that must be taken into consideration are: Carbon dioxide (CO_2); Methane (CH_4); Nitrous oxide (N_2O); Hydrofluorocarbons (HFCs); Perfluorocarbons (PFCs); Sulphur hexafluoride (SF_6). [9]

The inventory procedure is fundamental to the assessment. There are different methods of calculation according to the various procedures that can be adopted today, in this study was chosen that of the Carbon

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Footprint Standard Ltd as it allows you to have a certification and logo for three levels of analysis: Assesed, Neutral, Reduced. The Municipality is currently engaged in the procedure for the acquisition of the Carbon Footprint Standard - Assessed) [10].
The accreditation standard allows organizations, service structures and producers of goods to obtain a qualification corresponding to a certain international level, which attests to the level of emissions produced during the activity; as a result, customers acquire a higher index of confidence in the accredited as the entire process is approved, monitored and verified.
Once the procedure has been completed, organisations may use the "Carbon Footprint Standard" logo in order to witness and certify the level of emissions caused by their activities; these logos are trademarks of Carbon Footprint Ltd and may be used under licence, which is issued for a period of 12 months.
The Carbon Footprint Standard qualification is obtained by following specific procedures based on international and/or national calculation methods; for organisations, reference can be made to systems of their choice such as: WRI's GHG Protocol (Greenhouse Gas Protocol), BEIS Voluntary Reporting Guidelines (previously DECC); Nationally produced factors by goverment bodies; IEA for international country specific electric factors.
The procedure chosen in this study is the WRI's GHG Protocol (Greenhouse Gas Protocol) [11].

4. Methodology
Going into the illustration of the methodology adopted: the calculation of the Carbon Footprint Standard, referring to a specific territory, must take into account "at least" the energy consumption of buildings – during the operating phase – and those related to transport. For the purposes of quantifying the carbon footprint, an initial phase of data collection of the current situation is therefore necessary. The precise 360° description of the territory selected on a sample basis for the research experience summarised here is fundamental for the aforementioned territorial specificity. In this study, a small Municipality (Trevignano Romano in the Lazio Region) was chosen to represent 70% of the total 7,915 Municipalities in Italy; and within it, a portion – called Urban Cell – was identified with bound buildings and a consolidated urban fabric with limited possibilities of intervention both on buildings and on transport as they belong to historic centres [12].

4.1 Territorial analysis
The data on the total area of open spaces (A_{os}), the number of inhabitants (N_{inh}) and the number of buildings (N_{bui}) are necessary for the calculation of the index of open space area per inhabitant and per building, which can be expressed as the ratio between the total area of open spaces and respectively the total number of inhabitants (I_{sur_Inh}) and the total number of buildings (I_{sur_Bui}).

$$I_{sur\_Inh} = A_{os} / N_{inh}$$
$$I_{sur\_Bui} = A_{os} / N_{bui} \quad (1)$$

This index therefore takes into account the surface area of green space by enhancing the territories with a greater quantity of it. On the basis of the GHG Protocol procedure (and the respective calculation methods) chosen, the conversion factors have been adapted to the specific Italian conditions. The GHG Protocol guidelines require that greenhouse gas emissions be estimated by distinguishing between direct and indirect emissions:
- Direct emissions: from the direct combustion of fossil fuels used for heating, for the supply of transport vehicles and for the generation of electricity;
- Indirect emissions from energy consumption: emissions from the supply and combustion of fuels for the production of the electrical or thermal energy consumed;
- Other indirect emissions: emissions from products and services used including also greenhouse gas emissions related to the fuel supply chain.

4.2 Emission factor associated with the energy consumption of buildings
For electricity consumption in the building sector, the conversion factor F_1 [expressed in kg of CO_2eq per kWh of electricity produced] is obtained as an average of the amount of CO_2eq emitted per kWh of electricity produced on the basis of the fuel used (A, B, C, ..., n) weighted on the percentages of composition of the energy mix used to produce the electricity fed into the system (%A, %B, %C, ..., %n).

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$F_1=(A*\%_A)+(B*\%_B)+(C*\%_C)+(\ldots)+(n*\%_n)[kg_{CO2eq}/kWh_{electrical\ energy}]$ (2)

For thermal consumption, the quantity of fuel used is first calculated as the ratio between thermal consumption and the product between the overall efficiency of the heating system and the production of domestic hot water and the lower heating value of the fuel. The efficiency of the heating system depends on many factors, such as the type of heat generator and terminal devices, the year of installation, distribution system, etc. The conversion factor F_2, expressed in kg of CO_2eq per kg of fuel used, is obtained from the stoichiometric chemical reaction of combustion and depends on the type of fuel itself.

$F_2=M_{CO2eq}/M_{fuel}[kg_{CO2eq}/kg_{fuel}]$ (3)

M is the mass in the combustion reaction.

4.3 Emission factor associated with transport

For the transport sector, the conversion factor F_3, expressed in kg of CO_2eq per L of fuel used, is obtained as an average of the quantity of CO_2eq emitted per type of vehicle fuel (A, B, C, ..., n) weighted on the percentages of vehicles circulating per type of fuel ($\%_A$, $\%_B$, $\%_C$, ..., $\%_n$).

$F_3=(A*\%_A)+(B*\%_B)+(C*\%_C)+(\ldots)+(n*\%_n)[kg_{CO2eq}/L_{fuel}]$ (4)

The total annual emission of CO_2eq, as determined by the emission factors below, is derived from the following report:

$Em_{CO2}=(F_1*kWh_{electrical\ energy})+(F_2*kg_{fuel})+(F_3*L_{fuel})[kg_{CO2eq}]$ (5)

In this way, the carbon footprint is therefore assessed as the ratio between the total annual quantity of CO_2eq, calculated for the various sectors analysed, and the surface area indices of open space.

$CF_{inh} = E_{CO2eq} / I_{sur\_Inh}\ [kg_{\ CO2eq} / m^2]$

$CF_{bui}=E_{CO2eq}/I_{sur\_Bui}[kg_{CO2eq}/m^2]$ (6)

4.4 Data quality

The input data used for each of the emission factors (F_1, F_2, F_3 previously identified), are primary data as they are obtained from direct surveys processed by crossing results of on-site surveys, high-resolution satellite photos, data provided by the municipal administration and climate data.

The surveys carried out on the spot:

- Typology of summer and winter air conditioning systems in buildings;
- Electric and thermal energy consumption of buildings (resulting from the analysis of bills, or provided by the local distribution authority) expressed in kWh;
- Building characteristics (year of construction, orientation, form factor, m^2, m^3, type of construction and plant engineering);
- Number of vehicles in transit within the study area (detection by sensors or stations);

Satellite photos have been verified:

- Built-up area (area in m^2);
- Surface green spaces (m^2);
- Surface areas of practicability (m^2);

Data provided by the municipal administration:

- Number of inhabitants;
- Number of buildings;

Climate data:

- Climate Zone;
- Day degrees (difference between the outdor and indoor tempertuture during the winter period;
- Average temperature (°C);
- Average rainfall (mm/year);

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- Average horizontal solar radiation (kWh/year);
- Average wind speed (m/s).

Once the analysis of the initial situation has been completed, it ispossible to proceed with the proposal to intervene for the overall reduction of CO_2eq emissions or of the carbon footprint previously estimated, with the objective, once the interventions have been carried out, of obtaining the “carbon footprint standard reduced certification”.
The proposal for intervention with regard to buildings has been calibrated taking into account: the initiatives already underway in the Municipality; the Technical Regulations for Construction [13], the procedures for the cost-benefit analysis of energy retrofit interventions [14], the regulations in Italy for access to tax deductions relating to interventions for building renovations involving energy savings [15] and the Guidelines for interventions in buildings with historical-architectural constraints [16].
As far as transport is concerned, according to the Greenhouse Gas Protocol, the emissions are produced directly by the combustion of fuel or indirectly by the use of grid-supplied electricity. Collecting accurate data for transportation activities, calculating emissions and allocating these emissions to cities can be a particularly challenging process.
The methodologies for estimating transport emissions can be broadly categorized as top-down and bottom-up approaches.
Top-down approaches start with fuel consumption as a proxy for travel behavior. Here, emissions are the result of total fuel sold multiplied by a GHG emission factor for each fuel. Bottom-up approaches begin with detailed activity data. Bottom-up approaches generally rely on an ASIF framework for determining total emissions.
The ASIF framework relates to the: amount of travel Activity (A) is often measured as VKT (vehicle kilometres traveled), which reflects the number and length of trips; the mode share (S) describes the portion of trips taken by different modes; Energy Intensity (I) of each mode, fuel (I), often simplified as energy consumed per vehicle kilometer, and carbon content of the fuel, or Fuel factor (F), is primarily based on the composition of the local fuel stock.
Most cities start with top-down approaches and progress towards more detailed bottom-up methodologies that enable more effective emissions mitigation assessments and transportation planning. A robust inventory can use data under each approach to validate results and improve reliability. [11]
Following the illustration of the case study, the exposition will be concluded by reporting the results achieved and their possible developments.

5. The case study: the Municipality of Trevignano Romano

As mentioned at the beginning, the case study that is presented, located “today” and “within” a share of the Lazio territory (the municipality of Trevignano Romano), has the specificity that allows (as well as with foreign operators) to collaborate with adjacent municipalities. Located on the northern shore of Lake Bracciano, at an altitude of 173 meters above sea level, has an extension of 39.4 km^2, of which 99.9% is subject to landscape constraints. The expected population is 18,167, compared to 5,949 at the end of 2010. The Municipality has seen the development in recent years of a series of residential settlements, consisting mostly of second homes: therefore the structure of road infrastructure is deficient, inadequate compared to the traffic – moreover increased in the summer period – and burdened by the transit of heavy vehicles. The residential expansion in the territory has taken place since the 70s, through a series of private lots that make the spaces without general consistency and an urban design of any quality connotation.

5.1 Analysis of the territory

From the studies conducted and the publications produced also by those who write here [17] it was easy to analyze the territory with the necessary punctuality. Precisely because of the results of this research, today we can say that the territory can be divided into Urban Cells, fundamental for the analysis of the territory itself, because this partition facilitates the study and the work and is deduced (and confirmed) through the analysis of environmental and urban diversity.
In this way it is possible to identify four distinct Urban Cells according to the building characteristics of the building, the use of land and the number of inhabitants.

- Urban Cell 1: historical centre area
- Urban Cell 2: Lakeside area

- Urban Cell 3: Hilly/residential area
- Urban Cell 4: Expansion Zone

It was decided to work on Urban Cell 1, (Figure 1) (a term that will be used later) as a sample because of its urban structure and the presence of numerous constraints. The historical centre is more complex in terms of the architectural aspects of environmental protection and safeguarding (especially on the lakeside front), as well as for the achievement of energy improvement standards and consequent accreditation for the Carbon Footprint Standard.
The Urban Cell 1 covers a total area of 67,000 m² (of a total of 39.4 km^2 or 0.2%) and houses 112 buildings and 600 inhabitants (Table 1).

Figure 1. Urban Cell 1: Historical Centre of Trevignano Romano [Source: elaboration by Authors on Google Earth data].

Table 1. Data relating to the total area of the Urban Cell 1 and the relationships with respect to the built area, the green area, the number of inhabitants and buildings. Source: Elaborations by authors].

Data from Urban Cell 1	
Total surface area	67,000 m²
Building site area	22,059 m²
Open space surface	44,941 m²
Green area index per inhabitant	74.9 m²/inhabitant
Green area index for building	401.26 m²/building

In consideration of the orography (the altimetric surfaces are higher and increasing towards the north-east side, with lower altitudes than those of the built up area towards the south-west front, along the lake) there are overall climatic characteristics (minimum temperatures on average 9.6°C, maximum 19°C) and orographic characteristics influenced by the mitigation due to the presence of the lake; these conditions make the territory free of strong temperature ranges (Table 2).

Table 2. Climatic data of the Municipality of Trevignano Romano. Source: Authors elaborations on data: weather, D.P.R. n.412/1993, Città metropolitana Roma Capitale].

Climatic data of the Municipality of Trevignano Romano	
Climate Classification	D Zone
Degrees Day	1.605
Average temperature	15°C
Average rainfall	809 mm/year
Average solar radiation	1,514 kWh/year
Average wind speed	3.7 m/s

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5.2 Building analysis

With reference to the 112 buildings mentioned above (from the sample under study), there is a lack of homogeneity in the building, both in terms of size and structure, and a high concentration on the lake front, where the greatest number of renovations were carried out to allow for the inclusion of diversified commercial and accommodation activities. There is a diversification both in the openings (rectangular in shape, alternating with arched portals and curtain walls of *porticos*) and in the alignment of the road front not continuous, due to the truncation due to the insertion of pedestrian roads that allow the connection with the main road and the long lake. The same road fronts are typified by constant misalignments and backward movements due to the presence of spaces belonging to the various commercial services (Figure 2).

Figure 2. Roadside views with commercial activities. [Source: photo by Authors].

The year of construction of the buildings, almost all of which were built before 1945, is fundamental. Considering the types of buildings and, consequently, the presence of a historical constraint, it was necessary to analyse the buildings on a case-by-case basis, highlighting the morphological differences and the characteristics of the roofs, transparent surfaces and any presence of *porticos*, *patios* and fountains. This variability, apparently governed by aesthetic logic, is actually due to climatic requirements, to which the architectural and design choices also relate (Figure 3), with a considerable correspondence between particular architectural features and the climatic zone in which they arise. The Urban Cell 1 consists of 3-storey buildings, with an average surface area for a single housing unit of 80 m^2, made of load-bearing masonry in volcanic tuff, the wall thicknesses are between 50 and 80 cm covered externally with plaster and/or exposed bricks; 70% of the windows and doors have wooden frames and single glazing. Almost all of the systems are of an autonomous type with methane gas heating systems positioned outside each residential unit. The electrical systems for air conditioning are about 1 for every 2 residential units. For the buildings in the old town centre, it emerged that about 90% of them are powered by heating systems consisting of a natural gas boiler as a generator and radiators as terminals. The electrical and thermal consumption was obtained through the analysis of the energy bills of the buildings for the years 2015, 2016 and 2017. The average annual consumption of electricity, calculated as the average for the three years, is 1,665 MWh, while the average annual consumption of natural gas is 476,305.5 Nm^3.

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Figure 3. Views of the main city centre Urban Cell 1: residential activities [Source: photo by Authors].

5.3 Transport

Emissions from transportation sources in this study, are related only to road transportation:

- Emissions from fuel combustion on-road transportation occurring within the city boundary;
- Emissions from grid-supplied energy consumed within the city boundary for on-road transportation;
- Emissions from portion of transboundary journeys occurring outside the city boundary, and transmission and distribution losses from grid-supplied energy consumption.

In the Urban Cell 1 the driveways and pedestrian streets (Figure 4) are divided into:

Road link Trevignano Tomano with *Cassia bis*
Pedestrian street 1st level
Pedestrian street 2nd level
2nd level-secondary pedestrian street
Path-linking historic centre with *Rocca*
Centrality

Figure 4. Road types of the Urban Cell 1 [Source: elaboration by Authors on Google Earth data].

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The average annual distance by car has been calculated assuming two hypotheses: the first takes into account only the local section of road that can be travelled by car, of about 1 km (hypothesis A) and the other takes into account the fact that about 30% of residents go daily to the capital city for work, which is about 40 km away, and does so mainly by their own private vehicle (hypothesis B).
Therefore, the total CO_2eq emissions are the result of the sum of the emissions calculated in both hypotheses.

Hypothesis A
Following an analysis of local traffic, it was possible to break down the private vehicle count for the summer period (Table 3) and the winter period (Table 4). During the summer period (100 days a year), approximately 1,000 vehicles were counted per day, while for the remaining period of the year (265 days), 500 vehicles were counted.

(1,000 * 100) + (500 * 265) = 232,500 [km/year]

The analysis was carried out by setting up temporary stations equipped with traffic detection sensors, located along the only access road to the Municipality of travel by road, which runs alongside the Urban Cell under study.

Hypothesis B
Assuming 180 residents (30% of residents) who go to Rome every day for work (300 days a year) and who cover an average of 40 km, we can estimate an average annual distance of over 2,000,000 km.

(180 * 40 * 300) = 2,160,000 [km/year]

Table 3. Survey of the number of vehicles in transit during the summer period.

Vehicles in summer transit	
11 june 2018 (from 00 to 24 h)	832 vehicles
16 july 2018 (from 00 to 24 h)	1,152 vehicles
27 august 2018 (from 00 to 24 h)	982 vehicles

Table 4. Survey of the number of vehicles in transit during the winter period.

Vehicles in winter transit	
1° october 2018 (from 00 to 24 h)	572 vehicles
12 november 2018 (from 00 to 24 h)	412 vehicles
3 december 2018 (from 00 to 24 h)	631 vehicles
14 january 2019 (from 00 to 24 h)	539 vehicles
4 february 2019 (from 00 to 24 h)	505 vehicles

5.4 Calculation of the Carbon Footprint of the current situation
In this way, the carbon footprint will therefore be evaluated as the ratio between the total annual quantity of CO_2eq, calculated for the various sectors analysed (taking into account hypotheses A and B) and the surface indices of open space. To this end, it will be necessary in advance to identify the emission factors for the various types of consumption analyzed and for the different fuels used.

5.4.1 CO_2eq emissions associated with the electricity consumption of buildings
The F_1 CO_2eq emission factor of electricity production for the Italian electricity system, updated to 2017, is 290 grams per kWh of electricity produced, calculated on the basis of data provided by the Energy Services Manager (GSE) and the National Authority for Alternative Energy (ENEA). (Table 5)

$F_1 = (A * \%_A) + (B * \%_B) + (C * \%_C) + (\ldots) + (n * \%_n)$ [gr di CO_2eq/kWh]
$F_1 = (0 * 36.60\%) + (883.1 * 13.75\%) + (369.6 * 42.34\%) + (622.8 * 0.75\%) + (0 * 3.78\%) + (280.5 * 2{,}78\%) = 290$ gr di CO_2eq per kWh of electricity produced.
The CO_2eq emission associated with electricity consumption is therefore about 483 tonnes of CO_2 equivalent each year.

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1,665,000 * 0.29 = 482,850 [kg/year]

Table 5. Composition of the energy mix used to produce electricity in Italy in the year 2017 [Source: GSE] and quantity of CO_2eq emitted per kWh of electricity produced [Source: ENEA].

Fuel	Energy mix distribution	Amount of CO_2eq per kWh
Renewable source	36.60 %	0 gr.
Coal	13.75 %	883.1 gr.
Natural gas	42.34 %	369.6 gr.
Oil products	0.75 %	622.8 gr.
Nuclear	3.78 %	0 gr.
Other sources	2.78 %	280.5 gr.

5.4.2 CO_2eq emissions associated with the thermal consumption of buildings
Considering an average natural gas density, under standard conditions, of 0.72 kg/Nm^3, the average quantity of gas consumed in one year from the consumption provided by the bills is calculated.

476,305.5 * 0.72 = 342,940 [kg $_{\text{natural gas}}$/year]

Using an emission factor of 2.75 kg of CO_2eq per kg of natural gas in combustion, obtained from the combustion reaction of methane, the CO_2 emission associated with thermal consumption is just over 943 tonnes of CO_2 equivalent each year.

342,940 * 2.75 = 943,085 [kg/year]

5.4.3 CO_2eq emissions associated with transport
For the calculation of the emissions, the data of the vehicles circulating in Italy as of 1/1/2017 were analysed according to the type of fuel used and the CO_2eq emission factor per litre or kg of fuel associated with it. (Table 6).
The analysis showed that the CO_2eq emission factor per litre of fuel is 2.43 kg of CO_2eq.

$F_3 = (A * \%_A) + (B * \%_B) + (C * \%_C) + (\ldots) + (n * \%_n)$
$F_3 = (2.65 * 58.4\%) + (2.38 * 33.8\%) + (0.02 * 2.3\%) + (1.61 * 5.2\%) + (0 * 0.1\%) + (1.17 * 0.2\%) = 2.43$ kg of CO_2eq per litre of fuel.

Considering an average distance of a car of about 18 km with one litre (L) of fuel, each year we can estimate a quantity of CO_2eq emitted for each of the two assumptions made.

Table 6. Vehicles circulating in Italy as of 1/1/2017 for power supply [Source: Joint processing of the Autopromotec Observatory and the Federmetano Observatory on ACI data] and CO_2eq emission factor per litre or kg of fuel.

Fuel	Distribution of car fleet	Emission factor
Diesel	58.4 %	2.65 kg/L
Gasoline	33.8 %	2.38 kg/L
Methane	2.3 %	0.02 kg/L
LPG	5.2 %	1.61 kg/L
Electric	0.1 %	0 kg/L
Hybrid	0.2 %	1.17 kg/L

Hypothesis A
232,500 / 18 = 12,917 [L/year]
12,917 * 2.43 = 31,388 [kg/year]

Hypothesis B
2,160,000 /18 = 120,000 [L/year]
120,000 / 2.43 = 291,600 [kg/year]

5.5 Analysis of the results of the current situation

The total emissions associated with the energy consumption of buildings and private transport is about 1,457 tonnes of CO_2 equivalent (hypothesis A) and 1,718 tonnes of CO_2 equivalent (hypothesis B) (Figure 5). In detail, the emissions caused by energy consumption during the operating phase of the buildings are about 483 tonnes of CO_2eq for electricity consumption and about 943 tonnes of CO_2eq for natural gas consumption; transport, by private means, is responsible for emissions of 31 and 292 tonnes of CO_2eq for hypothesis A and B respectively (Figure 6).

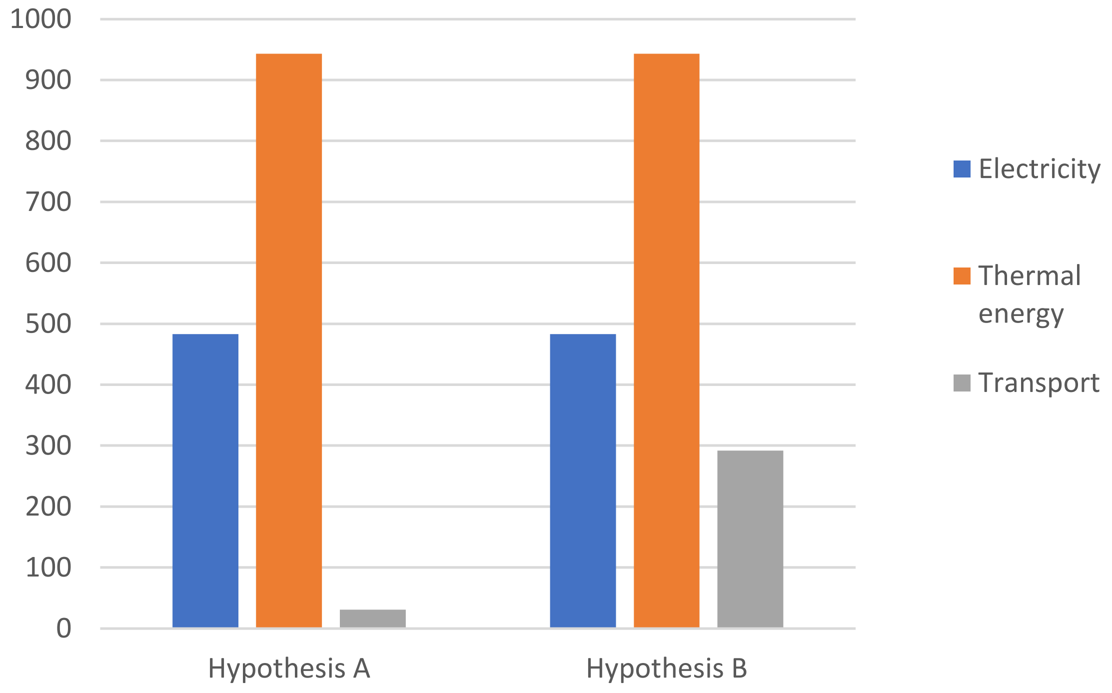

Figure 5. CO_2eq emissions in tonnes/year.

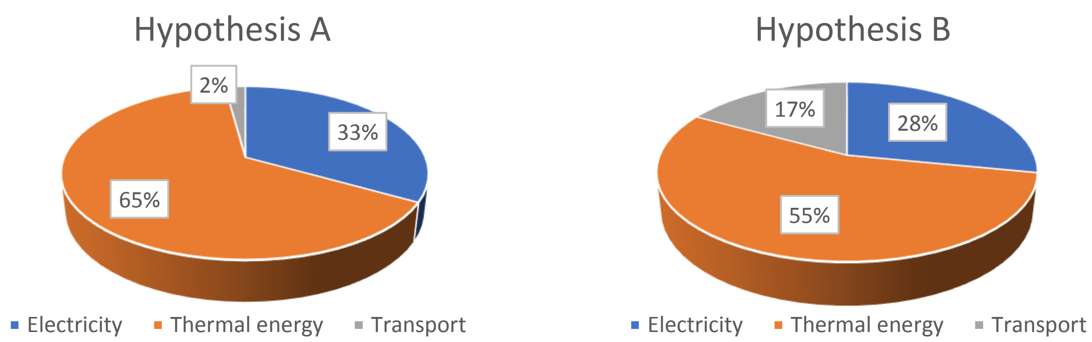

Figure 6. Percentage CO_2eq emissions by sector.

In both situations, the sector that contributes most to the emission of greenhouse gases is the thermal sector, referred to the heating of buildings, with percentages that exceed 50%. The carbon footprint of the historic centre of the Municipality of Trevignano Romano, using the index of open space area for each person and each building, has been estimated respectively at 19.45 and 3.63 tonnes of CO_2eq per inhabitant and per building for the hypothesis A. For hypothesis B: 22.94 and 4.28 (Figure 7).

Hypothesis A
1,457 / 74.9 = 19.45 [ton/m^2 per inhabitant each year]
1,457 / 401.26 = 3.63 [ton/m^2 per building each year]

Hypothesis B
1,718 / 74.9 = 22.94 [ton/m^2 per inhabitant each year]
1,718 / 401.26 = 4.28 [ton/m^2 per building each year]

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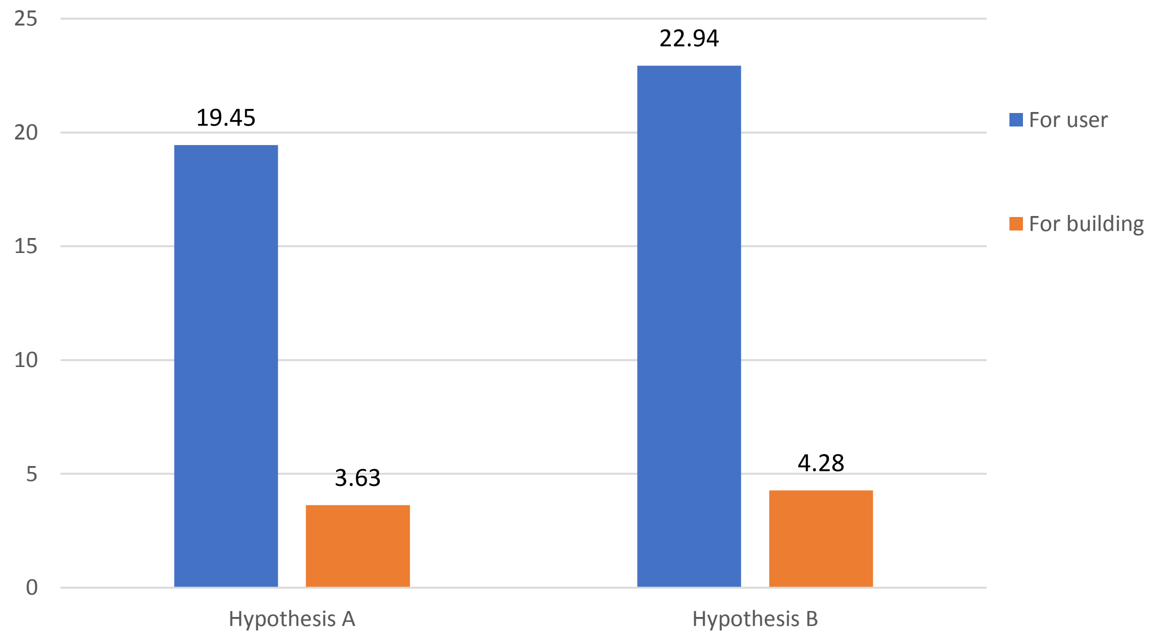

Figure 7. Carbon Footprint in tonnes CO_2eq/m^2 per inhabitant and per building.

5.6 Energy efficiency and emission reduction measures

Any intervention that is made within a context of historical, artistic or architectural value, requires a careful approach and thorough evaluation, which has as its purpose the preservation. Interventions concerning the improvement of energy efficiency should be considered as a means of protection, rather than a real modification of the asset itself. It should also be remembered (and rightly so) that for an economy of scale, energy compliance interventions, where possible, should be combined with other interventions of compliance, re-functionalisation, extraordinary maintenance, etc. The energy requalification of the cultural heritage has its roots in a widespread analysis, through which a diversified level of knowledge can be reached on various scales, from the territorial and landscape one, to the artistic-architectural one. It will not always be possible to meet the diverse needs of protection and architectural efficiency, so the design choices will be the result of a proper mediation, following a study "case by case" [16].

The quantification of the carbon footprint has been elaborated for Urban Cell 1, the main aspect of which is represented by the constraints imposed as a historic centre.

The starting point for the assessment to be made for the buildings is the knowledge of the heterogeneous information that derives from it:

- documentary and archival sources;
- bibliographic sources;
- direct and analytical observation of the buildings in their entirety (starting from the context to the typological and technological characteristics).

The final result of the historical analysis will allow a temporal reconstruction to be carried out with its subsequent constructive modifications, which have conditioned the structural and plant evolution, as well as its intended use. It is essential for the case study to consider only some of the applicable interventions for the energy improvement of the building. The procedure to be followed is based on preliminary actions, aimed at a correct energy diagnosis, after which the energy performance index of the actual state must be calculated. The diagnosis must also be used to evaluate possible improvement actions [18]. This evaluation of "comparison of analysis - evaluation" represents the pivotal point of the final design choices of intervention.

5.6.1 Identification of interventions

With regard to the possibility of reducing the consumption of energy from fossil sources using renewable sources, it should be borne in mind that the study area is characterized by an average wind speed of 13.3 km/h equivalent to 3.7 m/s equal to the minimum speed required for the operation of wind turbines, which is therefore lower in economic terms for the production of energy from wind sources (5 m/s). With regard to the use of solar energy, the territory is classified within the medium-high range, since the incident solar

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radiation of 1,500 kWh/m^2 on a horizontal plane, on the other hand, results in a low potential for solar collection due to the mutual shading of buildings and tree-lined areas, as well as an unfavourable ratio of volume and available surface area. Finally, the presence of the lake is not suitable for the exploitation of energy from water flow/hydropower, due to the lack of natural differences in level and the impossibility of exploiting the kinetic energy of water in fall or movement. From this evaluation, it follows that it is not suitable to install any kind of equipment for the production of renewable energy on site. As a result, the choice of measures falls within other sectors, such as buildings and transport.
Improvements in the energy performance of buildings are linked to the respect of the facades of the historic centre, most of which are made of exposed stone.
The most appropriate intervention, in order to limit heat loss, is the improvement of thermal insulation by placing the insulation outside the building, a strategic intervention to increase comfort conditions and energy savings, which will lead to a reduction in greenhouse gas emissions below; this intervention is rarely proposed for a historic building, if it is applied externally to the building.
The proposal is feasible, however, in the application of thermal insulation inside.
The intervention is carried out by applying a layer of thermal insulation, coupled with a plasterboard sheet or a counter-wall (lining) of brick blocks on the inside of the building. The choice of thermal insulation will also take into account the type of material, preferring natural ones with thermal conductivity between 0.030 and 0.045 W/(m*K) and density between 50 and 150 kg/m^3 (Tables 7, 8).

Table 7. Vertical section and characteristics of the load-bearing masonry before the redevelopment works.

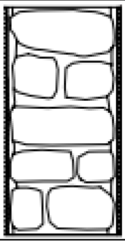
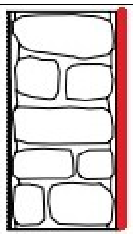
Vertical section masonry state of fact (current)			
	Material	Thickness (cm)	Transmittance average thermal (W/(m^2*K)
	stone blocks/brick bricks external/internal plaster in lime mortar	50 - 80 1-2	2,25 - 2,10

Table 8. Vertical section and characteristics of the load-bearing masonry after the redevelopment works.

Vertical section post-operative masonry (internal thermal insulation)			
	Material	Thickness (cm)	Transmittance average thermal (W/(m^2*K)
	stone blocks/brick bricks thermal insulation in wood fibre External/internal plaster in lime mortar	50 - 80 4 -10 1-2	0,5- 0,65

As far as windows are concerned, currently made of wood, single glass and average transmittance between 5-6 W/(m^2*K); the proposed intervention consists in replacing these windows, subject to respect for the morphological and architectural characteristics of the existing materials and finishes. A possible solution, therefore, is the use of a wooden frame with thermal break with thermal transmittance between 1.5 – 2.0 W/(m^2*K).
As far as transport is concerned, as described above, the Urban Cell 1 is bordered by the only access road to the Municipality, which connects it to the city of Rome; the remaining part is entirely served by a capillary pedestrian road network, widespread among the buildings. At present, it seems reasonable to intervene only on this road network, described in hypothesis A, since interventions on hypothesis B would imply infrastructural interventions not currently provided for in any Regional and/or National Plan.

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The proposal to use alternative means of transport only for hypothesis A therefore envisages, to discourage the use of private cars, within the perimeter:
- The replacement of the current means of urban public transport with electrically-powered vehicles: 2 shuttle buses with 20 seats serving the two existing routes, with an increase in the number of stops, such as to facilitate the use of the service (Figure 8).
More in detail, in route 1 - Movements within the municipal area, with strategic stops within the territory; in route 2 - Connection to neighbouring municipalities, in order to significantly reduce the incidence of traffic caused by the mobility of the inhabitants to the nearest railway station;
- Municipal bike sharing service that can initially provide a number of 30 bicycles, a number that could be increased. The network of special stalls is planned throughout the municipality in order to improve travel for short distances, facilitating the road network and relieving congestion in parking areas.

Figure 8. Municipality of Trevignano Romano, charging station for electrically powered vehicles - EnelX Project [Source: Photo by Authors].

5.7 Analysis of post-intervention results

The energy requalification of the buildings (thermal insulation of the walls and replacement of the windows), respectively, involves a reduction in the consumption of thermal energy of about 15-20% (5 and 10% compared to the pre-intervention situation). Assuming a percentage saving of 20% for masonry insulation and 10% for window insulation, it is estimated that the average annual consumption of natural gas will be reduced from 342,940 to 333,414 Nm3 with the consequent reduction in the carbon footprint (Figure 9).
With regard to the proposed interventions for the transport sector: proceeding on the basis of the two hypotheses identified during the analysis phase, we proceeded with the calculation of the new (reduced) value of the carbon footprint.

Hypothesis A

Analysing the 1 km road route that runs along the Urban Cell 1, during the winter period it is estimated that there will be a 5% reduction in the use of private vehicles; this value will increase during the summer period due to the increase in tourist flows, which reaches 15%, thanks also to the possibility of using a car park located at the entrance to the Municipality (2 km from the historic centre - Urban Cell 1), which allows private vehicles to park and the use of an electric shuttle bus to reach the historic centre.

Hypothesis B

The intervention may affect 10% of residents who could use the electric shuttle service and bike sharing to reach the nearest railway station, reducing the use of private transport to reach, for business reasons, the city of Rome (Figure 10).

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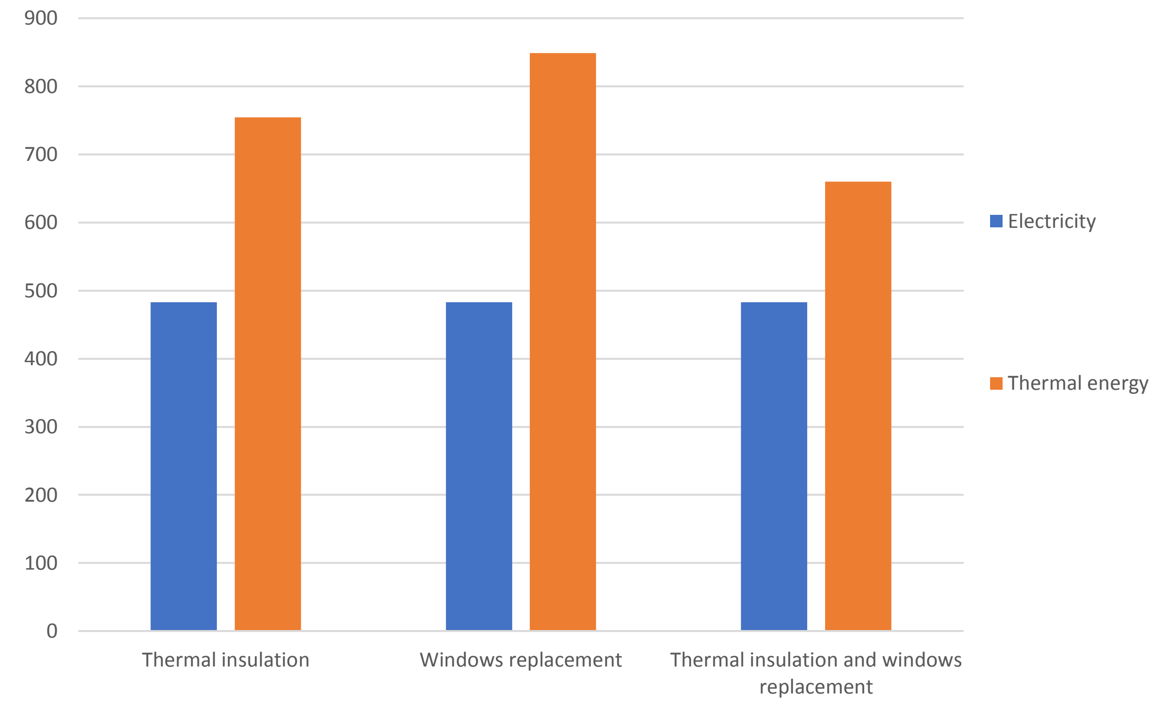

Figure 9. CO_2eq emissions in tonnes/year as a result of building interventions.

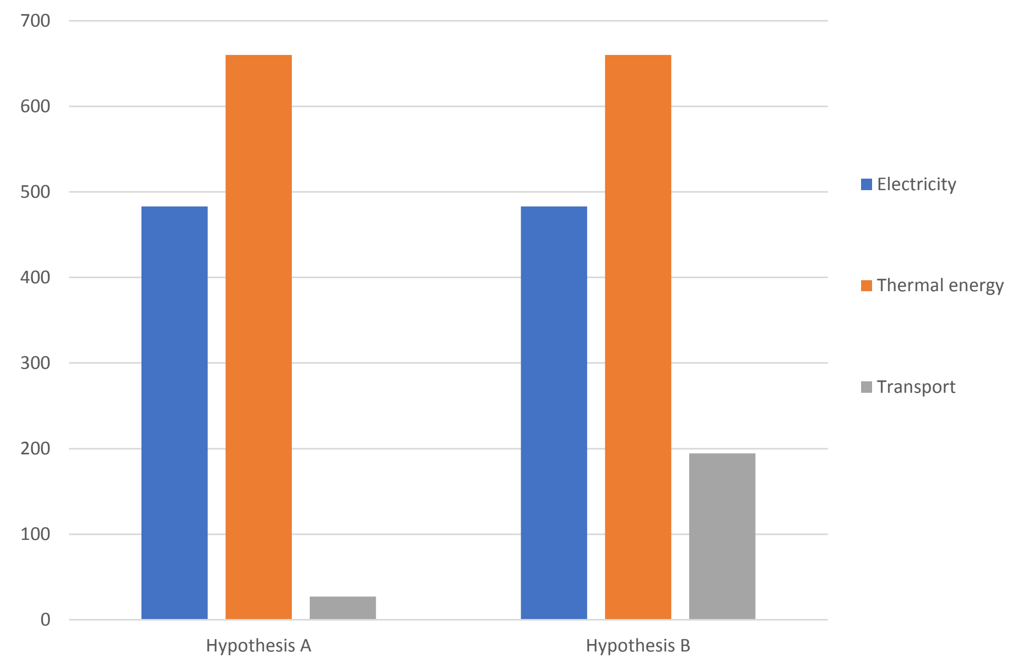

Figure 10. CO_2eq emissions in tonnes/year as a result of building and transport interventions.

5.8 Calculation of the post-operative carbon footprint

The carbon footprint of Urban Cell 1 of the Municipality of Trevignano Romano evaluated as the ratio between the total annual amount of CO_2eq, calculated as a result of energy efficiency measures of buildings and transport is equal to: (Figure 11).

Hypothesis A

1,170 / 74.9 = 15.62 [ton/m^2 per inhabitant each year]
1,170 / 401.26 = 2.91 [ton/m^2 per building each year]

Hypothesis B
1,337 / 17.85 = 22.94 [ton/m^2 per inhabitant each year]
1,337 / 401.26 = 3.33 [ton/m^2 per building each year]

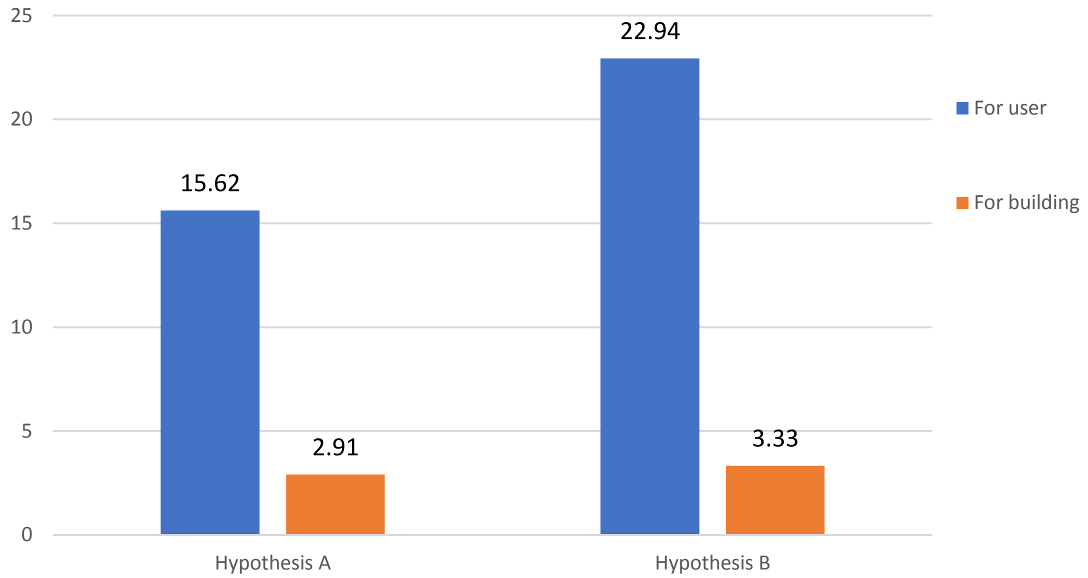

Figure 11. Carbon Footprint in tonnes CO_2eq/m^2 per inhabitant and per building following the interventions.

6. Conclusions
If the proposed reduction in the carbon footprint is confirmed: from 19.45 to 15.42 tonnes CO_2eq/m^2 per inhabitant each year (hypothesis A), and if therefore the Municipality intends to proceed, in the meantime it is possible to apply for the *Carbon footprint assesed* certification and after the *Carbon footprint reduced*, which – given the overall connotation of the context – constitutes an appreciable result.
Considering also – as mentioned in the introduction – that the issue of environmental sustainability is objectively more complex and very articulated because the criticalities that are found are rooted in political/economic/social options carried out “over time” and “in other locations. Critical issues that therefore “come from elsewhere and from afar in time” and that therefore can only denounce as partial the technical solutions that we try to propose today in the (naïve) conviction of solving the problems determined by them. But in the introduction we have also anticipated something else that it is good to resume here in closing. In this specific case, since on the one hand the readers are not Italian and on the other hand the possible operators could be foreigners, it is absolutely necessary (even leaving aside purely technical procedures and calculations) that the issues (or rather the problems) presented be “contextualized” “to the Italian reality” (correlating them to the model of economic/social/environmental development that is recorded there) but above all to the “today” in function of new laws and regulations being implemented and new needs that civil society expresses. The model can therefore be exported to other national (but also international) realities, offering adequate space also to foreign operators and entrepreneurs. In fact, how could foreign operators and entrepreneurs proceed – concretely – without knowing some Italian specificities such as: the transition of the building sector towards “4.0 industry”, digitalization, *dèbat publique*, public/private partnerships, the role of small and medium enterprises and, finally, a Code of Procurement that is constantly modified? Therefore, the question posed at the beginning was not wandering: Non-Italian operators, how much are they aware that the process of change in the construction sector essentially involves three key steps: digitization of the entire construction process; MMC - Modern Construction Methods (off-site production technologies to help minimize waste, inefficiencies, delays and errors by rediscovering quality and ability to predict); a transition from construction costs to cost-benefit analysis throughout the life cycle of the building? And above all – if you want to industrialize the construction sector – you have to comply (all standards, if possible) working not on a single building but at urban scale. It is repeated: beyond methods, procedures, calculations, the interest of this contribution – and the intent of those who proposed it – lies essentially in having rejected a “single

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and standard model" (valid everywhere but with little concrete results) in favor of a model contextualized to the national reality that is changing in the face of new economic, social and environmental needs.

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