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Indexes and indicators for the planning and decision-making process of the urban eco-energy system: the case study of the City of Turin

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Abstract

Climate change phenomena, environmental degradation and air pollution impacts represent a concrete threat to the human well-being of the future years, calling for immediate action by governors, who need to develop tailored policies to tackle these problems. In particular, the current paradigms of energy consumption, being one of the main causes of the above-mentioned problems, must be revised. Although efforts are needed at all levels of governance, urban policymakers can provide a significant contribution to the cause. In fact, even if cities only account for less than 2% of the Earth's surface, they consume 78% of the world's energy.

Dedicated science-based tools can provide an effective support to the decision-making process, helping in the development of appropriate policies. In this sense, a key role could be played by the definition of ad hoc metric systems, used both for assessing, in a quantitative and objective way, the current situation, which is essential for orientate the policies, and monitoring the evolutive trajectories of the urban energy systems, which is necessary to analyse the effect of the policies, quickly identifying issues and refocusing on priorities when needed.

An effective metric system, aimed at measuring the progress of urban areas towards energy transition, should take into account the multitude of related aspects which are of relevance at local level, by also capturing eventual cross-sectoral phenomena.

The scope of this work is then to provide, by means of a structured methodology, a comprehensive framework for measuring performances in the context of urban energy transition process, testing it through the case-study of Turin city.

In particular, the proposed methodology entails multiple steps. First, data-gathering and storage procedures used to build a dedicated database are described, also highlighting main decision criteria in the process of data collection. Secondly, the conceptual design of the database - characterized by a hierarchical, multi-domain structure - is shown; three main domains (energy system, environment, socio-economy) involved in the energy transition process are detailed through the definition of lower-level layers (sub-domains and fields). Then, multiple indicators are set for each field of the developed framework, basing on existing literature or by own definition. A selection of these – the core indicators – are normalized and aggregated, building aggregate indicators for the fields, sub-domains and domains of the framework, as well as a global aggregate index, the "Green Transition Index". Finally, to prove consistency of the proposed framework, statistical coherence between indicators and aggregate indexes is evaluated.

The results for the study case, focused on period 2014-2019, according to the data availability, besides providing useful insights on the multitude of analysed phenomena, show that aggregate indexes well represent the underlying indicators. Still, in some cases, a certain degree of trade-off occurs in the phase of aggregation, highlighting that aggregate indexes need to be considered together with simple indicators to draw accurate conclusions and provide effective information to the policy decision-makers.

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ACI	Automobile Club d'Italia
AFOLU	Agriculture, Forestry and Other Land Use
AMIAT	Azienda Multiservizi Igiene Ambientale Torino
APE	Attestato Prestazione Energetica
ARERA	Autorità di regolazione per energia reti e ambiente
BAT	Best Available Technique
CCS	Carbon capture and storage systems
CHP	Combined heat and power
CO2EH	CO2 emissions related to heat that is exported outside of the territory of the local authority
CO2GEP	CO2 emissions due to the production of certified green electricity purchased by the local authority
CO2IH	CO2 emissions related to imported heat from outside the territory of the local authority
CO2LPE	CO2 emissions due to the local production of electricity
CO2LPH	CO2 emissions due to the local production of heat
EEA	European environment agency
EFE	Local emission factor for electricity
EFH	Emission factor for heat
ETS	Emission trading scheme
EV	Electric Vehicle
FUA	Functional Urban Area
GCP	Gross City Product
GDP	Gross Domestic Product
GEP	Green electricity purchases by the local authority
GHG	Greenhouse gas emission
GSE	Gestore dei servizi energetici
GTI	Green Transition Index
GTT	Gruppo Trasporti Torinese
GWL	Global warming level
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
IREA	Inventario Regionale delle Emissioni in Atmosfera
ISPRA	Istituto superiore per la protezione e la ricerca ambientale
ISTAT	Istituto nazionale di statistica
LPE	Local electricity production
MUD	Modello unico di dichiarazione ambientale

NACE	Nomenclature generale des Activites economiques dans les Communautes européennes
NEEFE	National or European emission factor for electricity
PAH	Polycyclic aromatic hydrocarbons
PV	Photovoltaics
REC	Renewable energy credit
REPLICATE	Renaissance of Places with Innovative Citizenship And Technology
SPF	Seasonal Performance Factor
TCE	Total electricity consumption in the territory of the local authority
TSO	Transmission System Operator
WHO	World Health Organization

1 Introduction

1.1 Climate change and European policies

The 2019 European Green Deal set for the European community the ambitious target of reaching no net emissions of greenhouse gases by 2050, enabling for the development of a fair society based on a resource-efficient economy. In particular, the proposed target aims to tackle the problems of global heating and climate change, responsible of multiple environmental damages as well as deterioration of life conditions all over the world.
Based on the 6th assessment report by IPCC [1], the 1.1 °C temperature increase since 1850-1900, due to GHG emissions from human activities, has promoted more frequent extreme weather events such as heatwaves and droughts (Figure 1). These kinds of phenomena can have different impacts with respect to the different geographical location; concerning the whole European continent, for example, the IPCC has identified four key risks based on the different global warming level scenarios (GWL) of 2°C or 3°C. First, the climate change can be responsible for heat waves-related mortality and morbidity of people as well as the reduction of suitable habitat space for both marine and terrestrial ecosystems. Secondly, a large impact on agricultural production due to heat waves and drought phenomena is expected. The third key risk involves water scarcity which becomes relevant, especially for the regions belonging to Southern Europe, at 2°C GWL yet, while flooding and sea level rise due to melting of glaciers (4th key risk) could also be of importance above 3°C GWL.

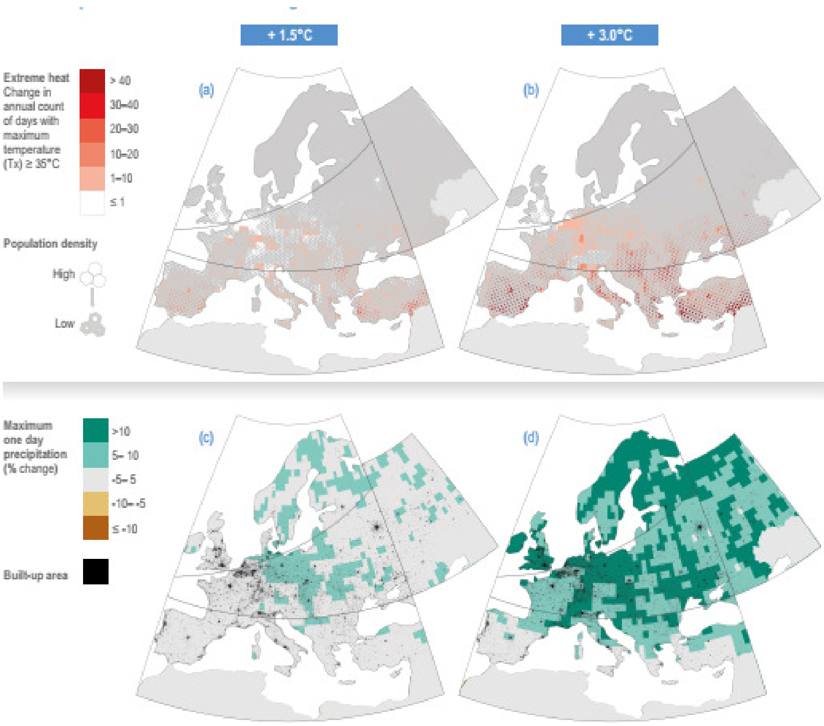

Figure 1. *Top: extreme heat. Change in annual count of days with maximum temperature (Tx ≥ 35°C). Bottom: Floods. Maximum one day precipitation (% change).*

The abovementioned risks call for an immediate action from the political entities, which should redesign the whole economical structure to become sustainable under the environmental point of view and reducing the possible impacts of climate change.

Concerning the European Union, the EU Green Deal, which was emitted in the wider framework of the global climate action envisaged by 2015 Paris agreement, represents a landmark in this sense. Besides setting the net zero emission target of greenhouse gases in 2050, it aims at decoupling economic growth from resource use, as well as protecting EU's natural capital and the health of citizens from environmental-related risks [2]. This requires the development of a set of policies necessary to address multiple targets, like the supply of clean, affordable, and secure energy, the transformation of the industrial sector to develop a circular economy, the improvement of energy efficiency in buildings, the shift towards a sustainable mobility and the reduction of air, water, and soil pollution.

Supplying clean, affordable, and secure energy represents perhaps the key point in the EU Green Deal. Indeed, the current energy system is too much dependent from the use of fossil fuels, whose combustion causes the release of large amounts of GHG emissions; as reported in [2], in 2019 the production and use of energy across economic sectors accounted for more than 75% of the EU's greenhouse gas emissions. Because of that, a transition towards an energy system based on low polluting energy sources, functional infrastructures and efficient energy end-use sectors is needed. However, to realize such energy transition process, it is fundamental to include all population groups, avoiding large disparities of energy cost across EU, and addressing, at the same time, the risk of energy poverty for households that cannot afford life-essential energy services.

Rethinking the whole structure of the industrial sector is also crucial for the purpose of developing a clean and circular economy, as industry accounts for 20% of EU's greenhouse gas emissions [2]. In particular, besides the need for decarbonization of energy intensive industries (steel, chemicals, cement), it has to be promoted a "sustainable product policy" through which reduce the amount of produced waste and increase the amount of recycled waste, minimizing environmental impact and climate change risks.

Energy efficiency improvements in transport and building sectors are needed as well. Concerning the transport sector, attention should be focused on increasing the production of sustainable alternative transport fuels, like renewable electricity and biofuels, promote the switching towards high-efficiency, low-emission vehicles and provide the related infrastructures (e.g. EV charging stations). The renovation of building sector, instead, should provide better energy performances of buildings also assuring a cautious use of involved mineral resources.

From these premises, it is evident that the pathway for reaching the 2050 goal of becoming the first climate-neutral continent, i.e. achieving net zero greenhouse gases emissions by balancing them so they are equal to the emissions that get removed through the planet's

natural absorption, is long and complicated: it is than fundamental to proceed step by step, setting intermediate goals.
In this sense, in 2021 the EU has promulgated the "Fit for 55" package through which it plans to reduce net GHG emissions by at least 55% in 2030, compared with 1990 levels.
The package, besides reproposing and deepen the elements contained in the EU Green Deal, also places different limits for GHG emissions from cars and "non-ETS" sectors as well as revising the ETS, for example by including the maritime transport sector in the emission trading mechanism.
On the other hand, through the financing of the research and innovation program Horizon Europe, EU is trying to address some of the difficult challenges in the energy transition process.
In view of this, the European Commission has launched different "EU missions" to mobilise and coordinate the different actions of public and private actors in a joint initiative which is directly funded by the EU.
In this context, one of the most ambitious and challenging missions regarding environmental safeguard and energy transition, is the "Climate-Neutral and Smart Cities mission" which aims at:

a. deliver at least 100 climate-neutral and smart cities by 2030;
b. ensure that these cities act as experimentation and innovation hubs to enable all European cities to follow suit by 2050.

In the following, a focus on the role of the cities in the energy transition and some of the main challenges to be addressed, are provided.

1.2 The role of the cities in the energy transition

Based on the definition adopted by EC [3], a city, also named as densely populated area, is a region where at least 50% people live in high-density clusters[1]. In the present society, cities represent the main place of aggregation of people and, consequently, of human activities; as reported in [4], 72% of the EU population lived in cities in 2015. This, of course, has an important impact on the localization of GHG emissions: estimates from United Nations [5], [6] suggest that even if cities only account for less than 2% of the Earth's surface, they consume 78% of the world's energy and are responsible for 75% of global CO_2 emissions, with transport and buildings sectors being among the largest contributors.
Moreover, due to the big level of people aggregation, cities suffer by the well-known problem of atmospheric pollution, which has direct consequences on people's health. Concentration of fine particulate matter $PM_{2.5}$ in the air gives a rough idea of the amount of atmospheric pollution across EU cities. According to World Health Organization (WHO), in order to protect health, the recommended maximum value for long term exposure of this pollutant is equal to 5 µg/m^3 but, considering studies from EEA [7], about 97% of the EU cities do not respect this limit.
From these data, it is more than evident that cities will play a pivotal role in the context of the future energy transition. The decarbonization of local energy systems will entail a range of different strategies which can be summarized in the three key points shown in *Figure 2* .

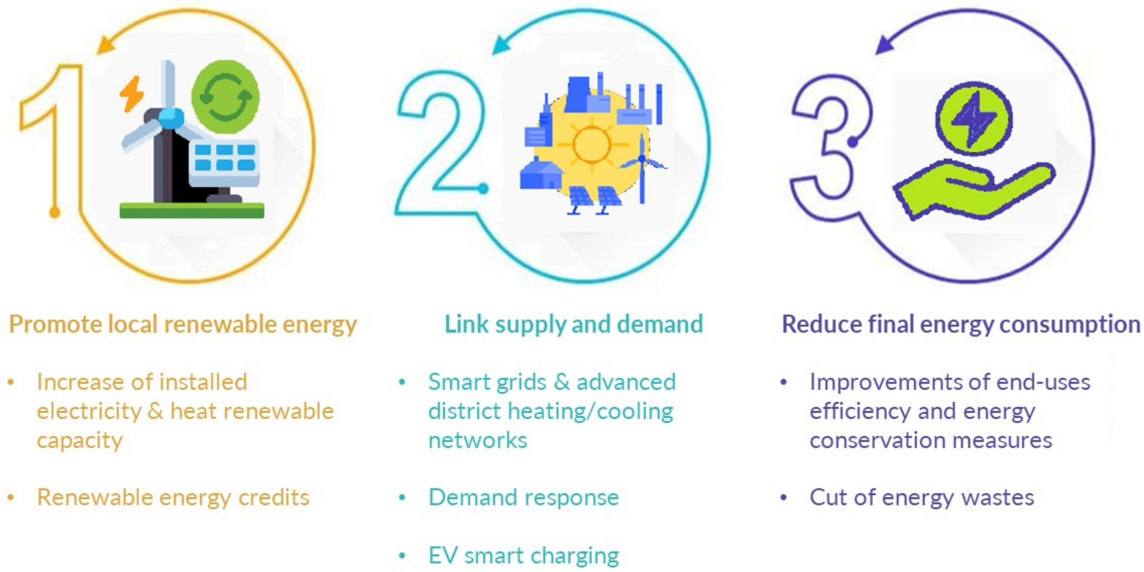

Figure 2. Key strategies for local energy transition

[1] High-density clusters are defined as contiguous grid cells of 1 km^2 with a density of at least 1500 inhabitants per km^2 and a minimum population of 50000.

The decarbonization process at urban level should begin with an attentive assessment of the potential of renewable energy production for the area. Photovoltaics, solar thermal plants and mini-hydroelectric and wind turbines could provide a substantial contribute to local renewable energy autoproduction. In particular, PV systems have become particularly convenient in the years, with a cost of electricity at PV module of 0.02 €/kWh [8]. However, as many urban areas are not particularly rich in terms of renewable energy resources, the option of buying renewable energy credits (RECs) should also be considered. RECs are market-based solutions certifying electricity is generated from renewable sources and, as better explained in paragraph 2.5.5, can be used to lower local emission factor of electricity.

Better linking supply and demand also represents a fundamental step in the process of decarbonizing cities. In fact, as renewable energy capacity increases, it is necessary that energy demand follows energy supply, avoiding curtailments of renewable energy production. In particular, cities, being areas characterized by many end-users having diverse patterns of energy consumption in time, represent the place where efficient coupling of supply and demand can be set up. For example, by means of demand response strategies, demand could be shifted in time reducing peak demand, beneficing the electricity distribution infrastructure and, if demand is shifted at time where renewable generation takes place, avoiding renewable energy curtailment. Another measure for coupling supply and demand is represented by smart charging, which consists in the chance of altering the charging cycle by external events, allowing for adaptive charging habits, and providing the EV with the ability to integrate into the whole power system in a grid and user-friendly way [9]. In particular, through bidirectional power flow EVs can act as energy storage systems, charging and discharging when most needed.

Of course, the strategies described above and, in general, an improved linkage between supply and demand can only be realized through the development of modern electricity distribution networks or smart grids, which, through sensors and intelligent devices (controllers, computers, automation systems) will manage power flows in an efficient way, coordinating and integrating the behavior of all the connected users. On the other hand, also advanced district heating/cooling systems can be of importance if the heat demand - which depends by urban topology - is particularly dense. Advanced district heating/cooling systems entail for example 4^{th} and 5^{th} generation networks, which are designed for low energy demands and lower water temperatures, as well as bidirectional energy flow, accommodating decentralized energy generation and distributing thermal energy where it is required.

Reduce final energy consumption is essential as well to provide urban decarbonization. In particular, cities are nowadays characterized by two main clusters of consumption, namely the buildings and transport sectors. A decarbonized buildings sector should entail a smaller use of fossil fuel-based heating/cooling plants, to be replaced by electric and/or district heating & cooling systems, and reduced energy consumption, to be obtained by means of renovations of the existing building stock as well as energy saving behaviors. For example, estimates in [10]

show that city largely relying on fossil fuel-based heating plants can reduce GHG emissions by 10-15% through heat pump deployment. Transport sector also plays an important role in decarbonization process. Cars, mopeds, trams, buses, vans and metro produce GHG emissions directly by combusting fuel or indirectly by consuming grid-delivered electricity. In the urban context, decarbonization can rely not only on the shifting towards carbon neutral options like electric vehicles, but also on the promotion of cycling and walking through the deployment of dedicated areas for the citizens.
All the aspects depicted so far show that urban energy transition is a complex process characterized by different underlying phenomena interacting each other. However, when considering the problem of urban planning, it is important to understand that a city is a place where other socio-economic and environmental challenges - like urban health, social segregation, mobility, water and waste management, air pollution and land use - are profoundly linked to the energetic dimension and therefore difficult to analyze separately (see Figure 3); the city level, in fact, represents the place where main societal changes occur, provoking large impacts on the surrounding environment.

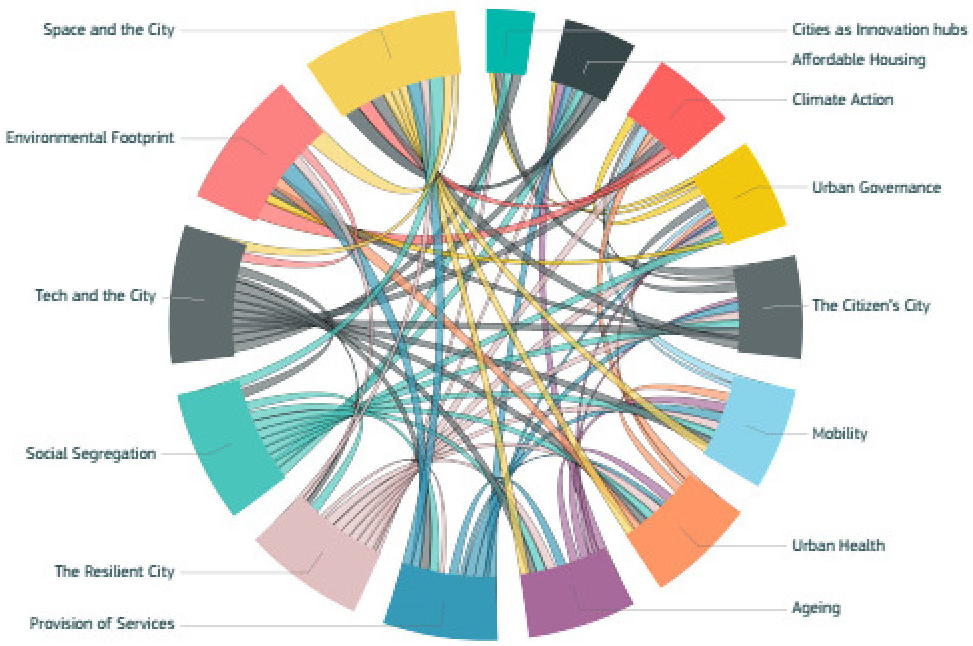

Figure 3. *Interlinkages among different challenges of a city* [11]

For example, the themes of mobility, land use, air pollution and urban health are profoundly interlinked among each other: a well-designed land use planning, based on efficient areas' interconnection and increase of green spaces, could be able to reduce both congestion and air pollution and providing a beneficial effect on urban health as well, as it lowers the chance of developing diseases related to air pollution exposure.

This means that future eco-energetic planning, which would desire to consider the multitude of sectors impacted by policies, should overcome the traditional "silo-structure" approach in favor of a "cross-sectoral" approach. The former, in fact, is characterized by a blind process of decision-making which only focuses on reaching a particular target in a certain sector, without considering possible inter-relations with other city dimensions. Instead, a cross-sectoral approach can respond in a concrete manner to the rising multi-sectoral city's challenges, enabling for a larger cooperation and coordination of the different political actors and assuring, at the same time, coherence in reaching the objectives across different policy areas.

Still, to respond in a concrete manner to the rising challenges of modern cities, policymakers need to be supported by consistent data. In this sense, thanks to the progress in cities' digitalization process, characterized by a larger penetration of cheap sensors and artificial intelligence, a lot of data have been made available to local administrations; these include for example measurements of local atmospheric pollution, traffic flow along main streets of the city, and various data for evaluating water and waste management.

If, on the one hand, this provides to political actors the opportunity of taking decisions in a more conscious manner, on the other dealing with a too large amount of data could represent a big challenge, not only in the process of gathering the most relevant ones, but also in their efficient utilization in order to provide good-quality services to the citizenship and develop structured policy planning able to consider the multidimensionality of the green transition process.

1.3 Aim of the thesis

The previous paragraph widely depicted the central role of the cities in the process of energy transition and the complexity of the multi-dimensional challenges that policymakers will be called to address in the next years.

As already highlighted, the development of ambitious policies requires, first of all, the collection, selection, storage and management of good-quality data to be used for:

a) the adoption of a metric system able to capture the most important aspects of urban energy transition, and
b) the feeding of models (e.g. simulation and/or optimization ones) which allow to analyse and compare possible future scenarios.

The two aspects coexist and complement themselves in the sense that, whereas the former is useful for "diagnosing" the current state of the urban system, as well as to quantitively track in time the energy transition process at urban scale, the latter is fundamental to investigate and evaluate alternatives in the phase of decision-making.

However, concerning the first aspect, an extensive literature review has demonstrated that a multi-dimensional metric system like the one suggested above has not been developed yet, as most of the indicators' sets created at urban level tend to focus on themes which are only partially related to energy transition, and/or ignore possible interrelations among the different dimensions involved in the process. For istance, Neves and Leal [12] propose a framework for measuring local energy sustainability by developing indicators along the energy chain (primary energy, final energy, useful energy and energy services) and relating them to the environmental, social and economic macro-dimensions, but lack of considering important themes in the urban context like water and waste management. The theme of local sustainability is also central in the work of Bonnet et al. [13], which propose a system of composite indices for French departments to evaluate them under the ecological and societal macro-dimensions; still, in this case, relevant indicators for measuring energy transition are missing, as the scope of the work was broader, and, also, little emphasis to cross-dimensional indicators has been given. This is also true for the framework of the project REPLICATE [14], which main goal was to deliver smart city business models based on the areas of energy efficiency, sustainable mobility and ICT, whereas other projects like CITYKEYS [15] and the ones reported in [16] mainly focus on the role of smartness and digitalization in cities.

The lack of a comprehensive framework for measuring energy transition at urban level is also linked to a poor use of the metric systems developed so far, which often consists in diagnosing the current situation to orient policymaking in the beginning of the planning process without providing a tracking in time of the analysed phenomena [12]. This, instead, represents a fundamental criterion of any ambitious energy planning, since measuring the effects of policies over time is required to compare them with the forecasts, and to recalibrate strategy if necessary.

The aim of this work is then to contribute to bridge these gaps, by proposing a multidimensional metric system based on indicators and aggregate indexes developed through a structured methodology. This also entails the setting of suitable data-gathering procedures, with the purpose of fostering continuous data collection and timely update of the selected metrics. The proposed framework is then used to analyse the study case of Turin city, describing trends for the various dimensions involved in urban energy transition, as well as highlighting possible data holes which will need to be filled to develop suitable energy policy planning.

2 Methodology

The present chapter shows the methodology adopted to create the database and the metrics useful to analyze the process of energy transition at urban level by means of a multi-dimensional approach.

First, the process of data management, needed to construct the database, and the classification of data typologies, required for defining the hierarchical relationship among data, are presented. Secondly, the conceptual design of the database, based on a multilayer structure, and the data formalization method, necessary to catalogue and track the collected data in a systemic and organic way, are explained. Then, the description of the full set of indicators is shown, and, finally, normalization and aggregation procedures are described.

2.1 The process of data management

Data management process is defined as the procedure used to extract and treat data to build the urban database. This process is articulated in four main steps:

a. Query of the data source, intended as a public or private entity which supplies information.
b. Access to a dataset, containing a certain set of data, provided by the data-source.
c. Extraction of data from the dataset. In this step, it is needed to explore the dataset and select the meaningful data.
d. Loading of the data in the database, which represents an aggregation of structured information in digital format. This step is the ultimate purpose of the entire process.

The database created by this process only contains data found through external sources; however, it could be further extended by means of another step which is:

e. Elaboration and aggregation of the data to build indicators and indexes, whose features are better explained in paragraph 2.2.

The whole process of data management is guided by many criteria for selecting the various data-sources, datasets and data. In fact, during the phase of data collection, it is quite common to find datasets which provide similar information; in this case it is important to choose reliable data-source and valuable sets of data to optimize the database's storage.

Since providing real-time tracking of the evolution of eco-energetic phenomena at municipal level is one of the main objectives of database's creation, database needs to be *continuously* updated with latest available data. As a result, it has been decided to mainly select data-sources which guarantee (at least in the intentions) the continuity of data-delivery service; in this sense, data provided by statistical institutes are quite reliable. Secondly, another important criterion for selecting datasets and data is that database has to be *automatically* updated. In fact, especially in the context of smart cities, where data are continuously collected from sensors placed around the city, the automation of data loading inside the dataset is necessary to provide the database with the most updated data. In particular, the process of automatic data loading inside the database can be realized by means of crawlers, preventing operators to often download a big amount of data. Because of this, in the phase of data collection, datasets having a format which is compatible with the automatic download system are prioritized.

2.2 Data typologies

In the view of creating a structured database characterized by a hierarchical structure, the definition of hierarchical data typologies allows to track the data management process described above, from the data-source to the elaborated data (indexes and indicators) and vice-versa.

The presented method, based on the work of Bompard, Desogus and Grosso "Formalizzazione della procedura di calcolo degli indici mediante un approccio standardizzato" [17], involves five data categories: raw data, basic figure, indicator, simple index, aggregate index.

a. Raw data: this category contains all the measured or not elaborated data, which are not indicators. This means that they are not useful to analyze the evolution of a certain phenomenon of the system which is analyzed. They have measurement units. Examples of raw data are:
    - Inhabitants number of a city, Pop [ab];
    - Municipal land extension, S [km^2];
    - Total waste generated, W_{tot} [ton];
    - Number of cars, Cars [car];
    - Bike roads extension [km];
    - Solar PV capacity [kW]
b. Basic figure: data elaborated by external sources which allows one to analyze the evolution of a certain phenomenon of the system which is analyzed; they have measurement units. Examples of basic figures are GHG emission amount by economic activity [ton] or the final energy consumption by sector [kWh];
c. Indicator: an indicator is a value obtained from a previous data elaboration which allows one to define the property of a system as well as to make comparisons with other systems. Indicators are not part of any scale, and they can or cannot have measurement unit. Furthermore, indicators, contrary to indexes, are not hierarchically classified; this means that an indicator can be obtained by the aggregation of multiple raw data and/or basic figures and/or other indicators.
d. Simple index: value without any measurement unit which is part of a graduated scale (0-1 or 0-100); it can be obtained:
    - From normalization of indicators;
    - From elaboration and normalization of data from an external source.
e. Aggregate index: value without any measurement unit which is part of a graduated scale. It can be obtained from the aggregation/combination of multiple simple or

aggregated indexes. Aggregated indexes are characterized by a hierarchical structure as well:

- Aggregated index of 1st level: obtained by the aggregation of multiple simple indexes;
- Aggregated index of 2nd level: obtained by the aggregation of multiple aggregated indexes of 1st level;
- Aggregated index of 3rd level: obtained by the aggregation of multiple aggregated indexes of 2nd level;
- Aggregated index of nth level: obtained by the aggregation of multiple aggregated indexes of (n-1)th level;

The hierarchical structure described above is, of course, necessary to distinguish among different kind of data. In particular, raw data and basic figures, which are the data typologies which can be obtained by data sources, only provide a specific information and are often useless for policy-making purposes. On the other hand, the elaborated data (indicators and indexes) have the valency of KPI and can be used to theoretically analyze the evolution of a property in real-time, providing a useful metric system to the political actors. For this reason, the distinction among indicators, simple and aggregated indexes is of primary importance. In fact, whereas indicators and simple indexes (and, thanks to the hierarchical structure, also basic figure and raw data) provide a quite refined information and can be used to specifically analyze a sectoral property, aggregate indexes represent the added value of combining different kind of information and show how different phenomena interact among each other.

2.3 Conceptual design of the database

The first step in the creation of a structured database for city-planning purposes in the context of the energy transition is to define a hierarchical structure which is needed to consider the multi-domain nature of the process. In particular, the need of defining such kind of structure derives from the multiple necessities of classifying the different kind of data, as well as to orient the huge process of data collection, which requires to operate rigorously to find the most relevant data and reducing as much as possible the chances of missing important ones.
As highlighted in chapter 1, the eco-energetic planning at local scale requires considering the possible inter-relations between different sectors. For this reason, three different domains, representing the macro-spheres in eco-energetic city planning process, have been identified:

- Energy system
- Environment
- Socio-economy

Again, due to the multi-domain nature of the energy transition phenomenon, it has to be noted that a domain can be inter-related with the other ones. Because of that, it can happen that collected data are assigned to more than one domain.
In order to specify the features of the collected data, it is necessary to define different sub-domains for each domain. Furthermore, each sub-domain can contain multiple fields which are used to further define the data. In the following, a short explanation of the identified subdomains and fields for each of the four main domains is provided whereas a comprehensive view of the conceptual design of the database is shown in *Figure 4*.

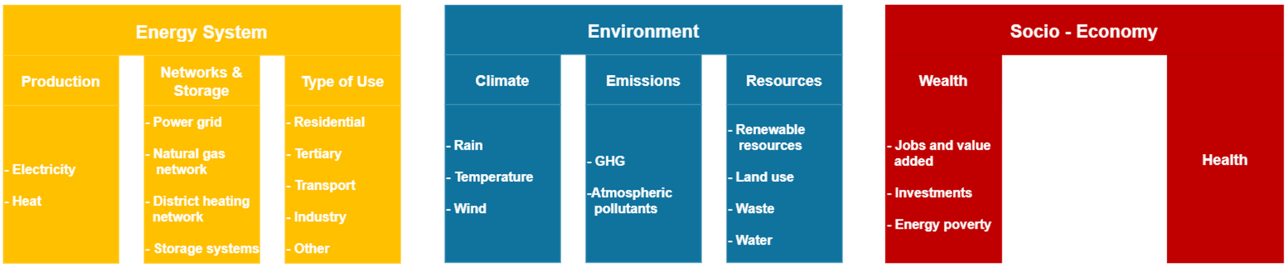

Figure 4. Conceptual design of the database

- **Energy system**

The energy system domain contains data related to multiple conversion phases of energy between supply and demand. However, it has to be noted that, since the scope of this hierarchical structure is to provide a framework for data collection in the sole municipal context, the classification shown here is not complete and has not the purpose and the features of a typical reference energy system (a simplified version for the case study can be found in Appendix). Instead, only the most significant phases in energy conversion process have been considered. In particular, the energy system domain is characterized by the following sub-domains (from a to c) and fields (from i to xi).

a. Production: it englobes all the data related to energy production facilities like yearly energy production and installed capacity. The identified fields are:
   i. Electricity: including electricity production facilities (e.g., solar PV, gas turbines, hydroelectric plants…).
   ii. Heat: involving heat production facilities (e.g., CHP units, solar thermal systems…).

b. Networks & Storage: this sub-domain contains data regarding the transport and distribution of energy carriers. The related fields are:
   iii. District heating: including data regarding district heating network such as the network extension, number of connected users, heat demand density, total thermal energy delivered and thermal energy losses.
   iv. Power network: containing meaningful data regarding power grid like losses and transformers' apparent power but also data on EV public charging systems which are considered as an extension of power grid.
   v. Gas network: includes data on natural gas losses in distribution network.

vi. Storage systems: including data related to distributed energy storage systems (e.g. residential-based energy storage batteries or thermal energy storage systems for district heating).

c. End-use sectors: this sub-domain relates to all the data regarding final energy use per-sector. The distinction among the different sectors, which is very similar to the one used by IEA in [18], is based on the following fields:

vii. Residential: involving all the activities related to private dwellings. It includes all-energy using activities in apartments and houses, like space heating, cooling, lighting, cooking and the use of appliances whereas personal transport is not included. Data classified in this field mainly regard energy consumption by commodity, residential floor area and number of dwellings, residential energy efficiency labels, building characteristics and age, typology of domestic heating/cooling system.

viii. Tertiary: includes activities from class G to class U of the Statistical classification of economic activities in the European Community (NACE rev.2) [19] which regard trade, finance, real estate, public administration, health, education, food and lodging and commercial services. Data classified in this field includes energy consumption by commodity and value added by typology of activity.

ix. Transport: involving data about private (e.g., cars, moto,…) and public (e.g., bus, metro, tram, trains,…) passenger transport as well as freight transport, such as number of cars by EURO classification and fuel or energy consumption and total travelled distance by category of vehicle.

x. Industry: data related to all the activities of class B and C of NACE [19], such as mining, quarrying and manufacturing. Meaningful data regard final energy consumption and ETS shares.

xi. Other: this field includes data about public lighting energy consumption as well as in the energy, water, waste, construction, agriculture, forestry and fishing sectors (classes of activities A and from D to F of NACE).

It has to be noted that the classification is quite similar with the one proposed by the guidelines of the Covenant of Mayors initiative [20] except for a further “municipal” sector, which englobes the activities of public administration, waste and water management and buildings owned by local authority.

- **Environment**

  The environment domain schematizes the interactions between the society and the natural resources.

  a. Climate: this subdomain contains the most meaningful data regarding meteorological conditions. The identified fields are:

i. Rain: referring to data about rain frequency (number of consecutive days without rain and rainfalls)
ii. Temperature: regarding seasonal temperature behavior and degree days
iii. Wind: data refer, for example, to yearly mean wind velocity.

b. Emissions: it contains data about anthropogenic and non-anthropogenic emissions. The classification is done by means of the fields:
iv. Greenhouse gases (GHGs): CO_2, CH_4, N_2O, HFC, PFC, SF_6, NMVOC
v. Atmospheric pollutants: PM_{10}, $PM_{2.5}$, NOx, SO_2, NH_3

c. Resources: the sub-domain considers different kinds of resources for human life, which are not necessarily energy related. The related fields are:
vi. Renewable resources, referring to renewable resources' information such as solar irradiance, wind speed and direction.
vii. Land use, which refers to data regarding land use change, namely the process by which the natural landscape is modified by human activities.
viii. Water, related to data about the process of water management until wastewater processing.
ix. Waste. Even if wastes are not properly defined as a resource, it has been decided to include this field in this sub-domain in the light of new industrial processes which allows the reuse of waste.

- **Socio - Economy**

The socio-economy domain involves the main data about economic activities, energy-related spending in families, and health. It is characterized by the following sub-domains:

a. Wealth: used to collect data regarding wealth creation in the municipal context; it includes various information regarding municipal population, jobs, incomes, economic activities, energy commodity prices, investments, value added. The related fields are:
   i. Jobs and value added. The field contains data about occupation and value added in energy and environmental-related sectors (classes D and E of NACE).
   ii. Investments. Data refer to investments, both public and private, for improvements of energy efficiency and infrastructures (like renewable-based energy sources and distribution networks), and, in general, for environmental protection.
   iii. Energy poverty. This field contains data regarding family spending for energy commodities.

b. Health: this subdomain is used to consider the adverse effects of atmospheric pollution. Data should be based on number of deaths and/or diseases related to atmospheric pollution.

2.4 Formalization process

The previous paragraph pointed out that, in the view of creating a multi-domain database that is regularly updated, it is required to collect a huge amount of data, diverse for typology and features; it is then fundamental to develop a structure to efficiently organize them in an organic way. This procedure, which is based on "Formalizzazione della procedura di calcolo degli indici mediante un approccio standardizzato" [17], can be considered as a sort of data-mapping and it is defined as formalization process.

The formalization process is particularly useful for obtaining a complete view of all collected data by organizing them in structured tables. In particular, basing on the process of data management and the distinction of the different data typologies presented in the previous paragraphs, formalization tables have been defined for datasets, downloaded data (raw data and basic figures), and elaborated data (indicators, basic and aggregate indexes). Each of these tables is characterized by two sections regarding respectively general information and particular information. General information regard:

- Data provider: the name of the entity which supply data/datasets;
- Name: the name of the dataset, downloaded data, elaborated data;
- Access: specifies if the access to the dataset is open or locked;
- Free: specifies if the dataset has to be purchased or not;
- Link: link to the webpage where dataset can be downloaded;

On the other hand, specifical information regard:

- Domain
- Subdomain: only specified for tables regarding downloaded and elaborated data;
- Fields: only specified for tables regarding downloaded and elaborated data;
- Format: format type of the dataset;
- Temporal granularity: specifies the frequency of records inside datasets;
- Spatial granularity: specifies the spatial aggregation level of records inside datasets;
- Temporal extension: temporal availability of datasets;
- Download: specifies if dataset is automatically downloadable or not;
- ID: identification code;
- ID Dataset: identification code of the dataset; it is used in the table of downloaded data for cross-reference between data and related dataset;
- Data typologies: specifies the data typology by the classification shown in paragraph 2.2;
- Notes: possible comments
- Formula: specified only for elaborated data
- Alphanumerical code: specified only for elaborated data and described below
- Description: specified only for elaborated data; it provides some information regarding the particular features of indicators and indexes

Table 1 shows the various attributes which can be assigned to the different information typologies, apart from domain, subdomain and fields whose features have been described yet.

Table 1. Formalization attributes

FORMAT		DATA CATEGORY		SPATIAL GRANULARITY	
EX	Excel	**d**	Raw data	**PS**	Punctual station
P	PDF	**b**	Basic figure	**Ad**	Address
G	GIS	**i**	Indicator	**PC**	Postal code
W	Webpage	**I**	Index	**C**	City
Z	Other format			**P**	Province
				R	Region
				Ct	Country

TEMPORAL GRANULARITY		FOR FREE		TEMPORAL EXTENSION	
h	Hourly	**Y**	Yes	**yyyy**	Year
d	Daily	**N**	No		
w	Weekly				
f	Fortnightly				
m	Monthly				
y	Annual				
S	Spot				

ID		ACCESS		DOWNLOAD	
DT	Dataset	**o**	Public (open)	**Auto**	Automatic
dd	Downloaded data	**c**	Closed	**Manual**	Manual
ee	Elaborated data				

To further characterize indicators and indexes, it has been developed an alphanumerical code (see *Figure 5*) composed by a prefix, a root and a suffix. In particular, the prefix defines the domain, subdomain and, if necessary, the field of belonging, the root is the symbol assigned to the indicator/index, and the suffix represents the data category (basic figure, indicator, simple index, aggregate index of n level).

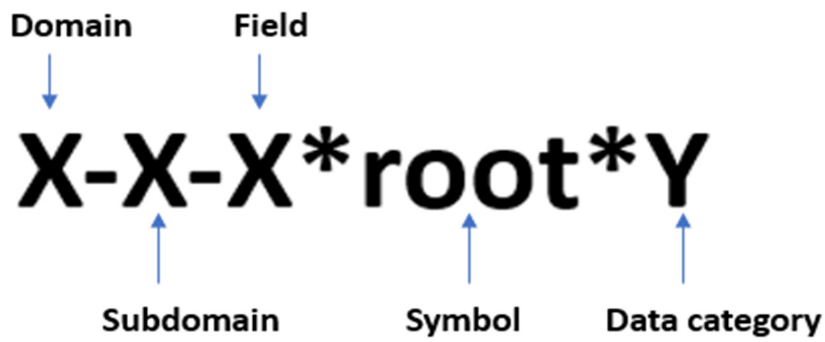

Figure 5. Alphanumerical code for indicators and indexes

The attributes for prefix and subfix are reported in the Appendix. The prefix is characterized by three (domain, subdomain and field) or two elements (domain and subdomain) separated by the character "-", whereas prefix, root and suffix are separated by the character "*".
For simplicity, in paragraph 2.5, only the prefix of the alphanumerical code for the selected indicators has been reported for each indicator.

2.5 Development of urban metrics

The purpose of this paragraph is to show the logic behind the development of indicators useful for urban eco-energetic planning.
In general terms, an indicator is a quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions (e.g. of a country) in a given area [21]. The purposes of building indicators are various: indicators can be used to track changes and identify trends of certain phenomena, to highlight weakness and strengths of a system and consequently drawing attention to specific issues and/or setting policy priorities, as well as to define benchmarks and to monitor system's performance across different units. For example, the process of urban waste management can be compared among different cities, possibly identifying BATs as well as enhancing the share of information to improve efficiency and reduce costs.
However, when dealing with the process of building indicators, three fundamental aspects must be considered. Firstly, it is important to have a limited but complete number of indicators. Indeed, although a large amount of indicators would provide a high level of detail on the analysed phenomena, it could appear more dispersive and create difficulties in understating the delivered key messages. The second aspect, instead, is related to the target of indicators themselves. Given that indicators are developed with the aim of supporting policymaking, the set of metrics should only consider phenomena that can be addressed by decision-makers at the urban level. For example, data regarding the price of energy commodities whose dynamics

are not dependent and cannot be influenced by urban policies, are not useful for the aim of this study.
Finally, according to the classification of data typologies made in paragraph 2.2, in case of choosing aggregate indexes instead of simple indexes and indicators, another crucial aspect to take into account is to which level should be carried on the aggregation process.
As explained in paragraph 2.2, an aggregate indicator is composed by a set of individual indicators, compiled into a single index, on the basis of an underlying model. The advantage of indexes is that they allow to evaluate complex phenomena, by capturing their multi-dimensional aspects and synthesizing the information in a compact manner and by means of a unique value. On the other hand, precisely because of this characteristic, they may invite policymakers to draw simplistic analytical or policy conclusions, and if badly constructed or interpreted, they can send misleading policy messages. *Table 2* shows main pros and cons of using aggregate indexes.

Table 2. (Adapted from [21]*)*

Pros and Cons of Aggregate Indexes	
Pros:	Cons:
• Can summarise complex and multi-dimensional realities in a comprehensive view to support decision-making. • Are easier to interpret than a set of different indicators. • Can assess progress of cities over time. • Reduce the visible size of a set of indicators without dropping the underlying information base. • Facilitate communication with general public (i.e. citizens, media, etc.) and promote accountability. • Help to construct/underpin narratives for lay and literate audiences. • Enable users to compare complex dimensions effectively.	• May send misleading policy messages if poorly constructed or misinterpreted. • May invite simplistic policy conclusions. • May be misused, e.g. to support a desired policy, if the construction process is not transparent and/or lacks sound statistical or conceptual principles. • The selection of indicators and weights could be the subject of political dispute. • May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action, if the construction process is not transparent. • May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored.

To further orient the process of metric development, an extensive literature review of the current frameworks of indicators used at urban level, in the context of energy transition, has been carried out. The results showed that the majority of the current sets of indicators in use are related to the topics of smart cities and sustainability, with a predominance of not-aggregated sets of indicators. In particular, among the different indicators sets presented in

[22], only one over 70 targets energy transition. *Table 3* summarizes the most relevant sets of urban indicators for eco-energetic planning purposes.

Table 3. Literature review of urban set of indicators

Name of the project/paper	Description	Aggregate (A) / Simple (S)
ISO37120: Sustainable development of communities – Indicators for city services and quality of life	A set of standardized indicators provided by ISO which measures city performances across 17 themes (economy, education, energy, environment, finance, fire and emergency response, governance, health, recreation, shelter, solid waste, telecommunication, transportation, urban planning, wastewater and water and sanitation).	S
REPLICATE [14]	KPI framework containing 56 indicators classified under seven dimensions (City description, Energy and Environment, Mobility and Transport, Infrastructure, Governance, Social, and Economy and Finance).	S
CITYkeys	Project aimed to develop a holistic performance measurement framework for future harmonized and transparent monitoring and comparability of the European cities activities during the implementation of Smart City solutions. Performances are evaluated across 5 themes: People, Planet, Prosperity, Governance and Propagation.	S
Energy sustainability indicators for local energy planning: Review of current practices and derivation of a new framework [12]	18 core indicators used to measure sustainability at municipal level, distinguishing between state (focusing in assessing the physical state of local energy system) and policy indicators (assessing the mechanisms provided by local authority to achieve sustainable targets) across the energy chain.	S
Evaluating Sustainable Development by Composite Index: Evidence from French Departments [13]	The sustainable development is indagated at local level by means of 6 composite indices, normalized through the min-max method and weighted and aggregated with arithmetic mean.	A

From these premises, it has been decided to adopt a “mixed” approach in developing metrics which consists in defining a set of *core* indicators which are normalized, weighted and aggregated, following the logic explained in paragraph 2.2, and another set of *supporting* indicators, which provide additional information and insights into specific phenomena. In the following, an extensive, field by field, explanation of the full set of indicators is presented.

Each indicator is characterized by a *"ID-code"*, as defined in paragraph 2.4, whereas the selection of core indicators and the aggregation process is further described in paragraph 2.6.

2.5.1 Energy System - Production

Indicators related to energy production sub-domain regard the penetration of renewable energy sources in the energy mix of the municipality in terms of both capacity installed and energy generated. To perform a classification of the different renewable energy sources, it has been decided to follow the rules provided by Eurostat in "*Renewable and Wastes annual questionnaire"* [23] and also used by GSE to quantify the usage of renewable sources in the national energy mix. In particular, GSE classifies renewable energy sources distinguishing among three sectors: electrical, thermal and transport. For the present purpose, only electrical and thermal sectors (which corresponds to the identified fields under production sub-domain) have been considered, given that transport sector is mainly related to the usage of biofuels which are difficult to account for and not so relevant in the municipal context. *Figure 6* provides a global view of renewable energy sources classification.

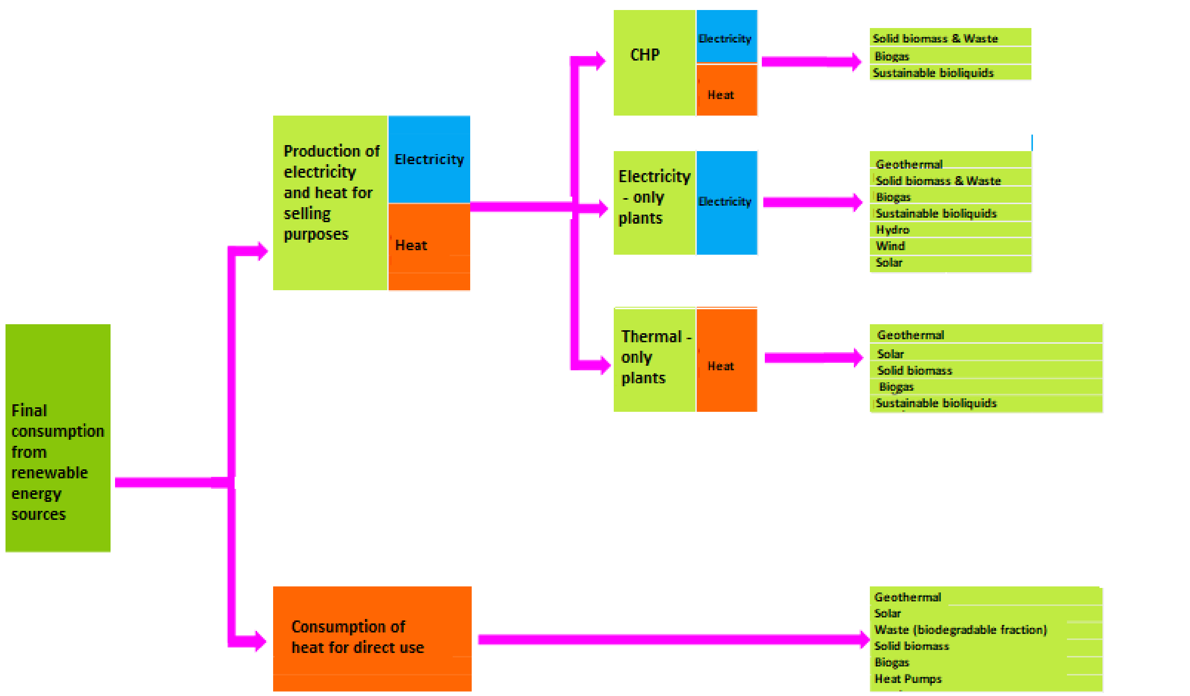

Figure 6. Classification of renewable energy generation (adapted from [24]*).*

It can be seen that final consumption from renewable energy sources is calculated as the sum of the renewable production of electricity and heat. Concerning the electricity production, the following elements are taken into account:

- Gross electricity production by hydropower
- Gross electricity production by wind power

- Gross electricity production from sustainable pure bioliquids
- Gross electricity production from sustainable blended bioliquids (renewable portion only)
- Gross electricity production from biogases[2]
- Gross electricity production from solid biomass[2]
- Gross electricity production from geothermal, solar (photovoltaic and thermal), tide, wave and ocean, biodegradable fraction of municipal waste.

Of course, in the case of municipalities, only some of the above-mentioned energy sources are of relevance. In particular, electricity production from solar plants, biogas, wind, and hydropower (in some cities mini-hydro power plants are quite diffused) are the most significant, while the other sources are usually not so relevant. A separate mention should be done for electricity generation from waste, which are not considered as renewable source apart from the biodegradable fraction. However, this last one is usually not used for power generation but sent to composing plants. This means that, in the case of waste incineration plants installed within the city boundary, the amount of renewable generated electricity accounted for is only the fraction produced from the biodegradable fraction of municipal waste, which is typically very small and could also be neglected in first approximation.

Concerning the thermal sector, for which the accounting of energy production is way more complicated than the electricity sector, a further distinction in the classification of renewable energy sources is done. This relates to the destination of the produced thermal energy which could:

- be sold to third parties (*derived heat)*, directly or by means of district heating networks. In this case, usually waste and biomass/bioliquids/biogases plants are of interest.
- be directly used for final consumption. Main examples are residential consumption of thermal energy from heat pumps, solid biomass plants, solar thermal collectors and geothermal plants.

Furthermore, it should be noted that in the case of direct use of heat, the whole energy content (i.e. the lower heating value) of the renewable energy source should be taken into account, whereas in the case of derived heat, it must be considered only the quantity of produced heat (the result of the process of energy conversion). Summarizing, for the thermal sector it should be considered the production from geothermal, solar, biodegradable fraction of waste, solid biomass, sustainable bioliquids, biogas, and the share of ambient heat used by heat pumps. In particular, as explained in Directive 2009/28/CE and Decision 2013/114/UE, only heat pumps with a SPF higher than 2.5 must be considered in the calculus.

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[2] For electricity produced from biogas/biomass in installations with a total rated thermal input equal to or exceeding 2 MW, biogas fuels can only be accounted if they fulfil the sustainability and greenhouse gas emissions saving criteria laid down in Article 29, paragraphs 2 to 7 and 10 of the Directive EU 2018/2001.

From these premises, the following indicators have been defined.

- **Electrical (ES-P-EL), thermal (ES-P-TH) and aggregate (ES-P) energy generation from renewable energy sources** (RSG^E, RSG^T, RSG) **[GWh]**

$$RSG^E = \sum_{i=1}^{n} RSG_i^E \tag{2.1}$$

$$RSG^T = \sum_{i=1}^{n} RSG_i^T \tag{2.2}$$

$$RSG = \sum_{i=1}^{n} \left(RSG_i{}^E + RSG_i^T \right) \tag{2.3}$$

where RSG^E is the gross electric energy production [GWh], RSG^T is the gross thermal energy production [GWh], i represents the typology of renewable energy source described above and n is the total number of typologies of renewable energy source listed above.

- **Percentage of renewable energy production on final energy consumption** RSP [%] **(ES-P)**

$$RSP = \sum_{i=1}^{n} \frac{RSG_i^E + RSG_i^T}{E_{tot}} \cdot 100 \tag{2.4}$$

where E_{tot} is the total municipal energy consumption [GWh] calculated as

$$E_{tot} = \sum_{j=1}^{n} E_{r,j} + E_{o,j} + E_{t,j} + E_{tr,j} + E_{in,j} \tag{2.5}$$

being $E_r, E_o, E_t, E_{tr}, E_{in}$ the final energy consumption [GWh] in residential, other, tertiary, transport and industry sector respectively and being j the energy commodity out of the n energy commodities available in the municipality.

- **Percentage of PV installed capacity out of installable capacity** PV_{cap} [%] **(ES-P-EL)**

$$PV_{cap} = \frac{C_{PV}}{Cmax_{pv}} \cdot 100 \tag{2.6}$$

being C_{PV} the total installed capacity of photovoltaic power systems [kW] and $Cmax_{pv}$ the potential capacity installable in the municipality [kW]. Whereas C_{PV} is a variable quite easy to be determined, data or analysis regarding $Cmax_{pv}$ are usually difficult to find. However, the indicator is quite significative not only to track the progress in increasing PV capacity, but also to compare this phenomenon with the potential of the area.

2.5.2 Energy System – Networks & Storage

The set of indicators developed for the sub-domain of Networks & Storage includes metrics to evaluate power grid quality and progress in grid integration of electric vehicles, losses in power grid and district heating network, and aggregate capacity of installed storage systems (both for electrical and thermal energy).

The quality of power grid distribution systems is defined by ARERA (Del. 566/2019/R/eel) which regulates service continuity, voltage quality and investments in power grids, through [25]. To evaluate power grid quality, two indicators are used:

- **Average number of interruptions per LV (low voltage) user N1** [-] **(ES-N&S-PG)** which measures the number of interruptions without notice, briefs (during more than 1 second and less than 3 minutes) or long, due to power distributor.
- **Cumulative length of interruptions per LV (low voltage) user D1** [-] **(ES-N&S-PG)** which measures the average number of minutes of interruption for long interruptions without notice due to power distributor.

In particular, ARERA defines for these indicators target values in relation to the population of the municipal area: municipalities with more than 50,000 inhabitants (high concentration), more than 5,000 inhabitants (average concentration) and less than 5,000 inhabitants (low concentration).

Concerning other indicators in this sub-domain, the following ones have been defined:

- **Losses in power grid PGL** [%] **(ES-N&S-PG)** calculated as the percentage of the total electricity distributed.
- **Losses in district heating network DHL** [%] **(ES-N&S-DH)** calculated as the percentage of the total thermal energy immitted in the district heating network. Losses in district heating network mainly depend on the level of insulation of district heating pipes and network topology, but also on ambient temperature. Because of that, this indicator should be considered in pair with information regarding degree-days.
- **Number of charging points per plug-in electric car** PG_{PEV} [-] **(ES-N&S/FU-PG/Tr).** The indicator is a measure of grid integration of electric vehicles, the higher the better. It is calculated with the following:

$$PG_{PEV} = \frac{PG_{chargers}}{Car_{PEV}} \tag{2.7}$$

where $PG_{chargers}$ represents the total number of electric vehicle public chargers in the municipality and Car_{PEV} the total number of plug-in electric cars.

- **Percentage of charging points supplied with renewable energy source (ES-PR/N&S/FU-El/PG/Tr) EV_{RES} [%].** The indicator EV_{RES} shows the percentage of electric chargers directly supplied with renewable electricity.
- **Total capacity of electrical (thermal) energy storage systems St^E (St^T) [MWh or m³] (ES-N&S-St).** The indicator St^E (St^T) is calculated as the sum of the capacity of electrical (thermal) energy storage systems inside the municipality which mainly are distributed storage systems like PV-coupled residential batteries or, in the case of storage systems for district heating, large reservoirs for hot water storage.

2.5.3 Energy System – End-use sectors

The main purpose of indicators in "End-use sectors" sub-domain is to analyse trends in energy consumption for each field (end-use sector) and, where possible, to provide a clear picture of the drivers of change in energy consumption. This can be done, firstly, by developing indicators of energy intensity and, secondly, by adding relevant indicators for each field.

Energy intensity is defined as the amount of energy consumed per activity or output for sub-sectors and end uses [18], and it is usually calculated as energy consumed divided by an economic indicator, like gross domestic product or total value-added by sector.

However, energy intensity could also be evaluated by dividing the energy consumption with a meaningful sectoral-activity indicator like, in the case of transport sector, the total distance travelled in a year or, in the case of residential sector, the total residential heated-surface.

In general, energy intensity is not coincident and should not be confused with energy efficiency. The difference between energy efficiency and energy intensity lies in the fact that, whereas the first indicator is related to the capability of a certain system to deliver a given output (performance, service, goods or energy) with a given amount of energy input and it is only related to the technology itself (e.g. an electric motor delivers a larger amount of translational energy compared to an internal combustion engine with the same amount of energy input), the figure of energy intensity includes different factors apart from energy efficiency. For example, when evaluating energy intensity of two countries as the ratio of the energy consumption and GDP, a higher energy intensity of one of the two countries does not necessarily mean that a country is more efficient than the other, since the structure of the two economies also influences the value of energy intensity (an economy mainly structured on the tertiary sector would consume less energy than an economy structured on the industry sector).

In the context of energy policymaking, one of the targets of analysis should be efficiency-based indicators, given that they provide meaningful information regarding the technological improvement in the various sectors. However, energy efficiency is quite difficult to be estimated since it requires separating the impact of all the different factors which are included in energy intensity and, also, very detailed data which are difficult to retrieve. Because of that, in the following, energy intensity is used as a proxy variable for energy efficiency and computed following the pyramidal framework explained in [18] and shown in *Figure 7* .

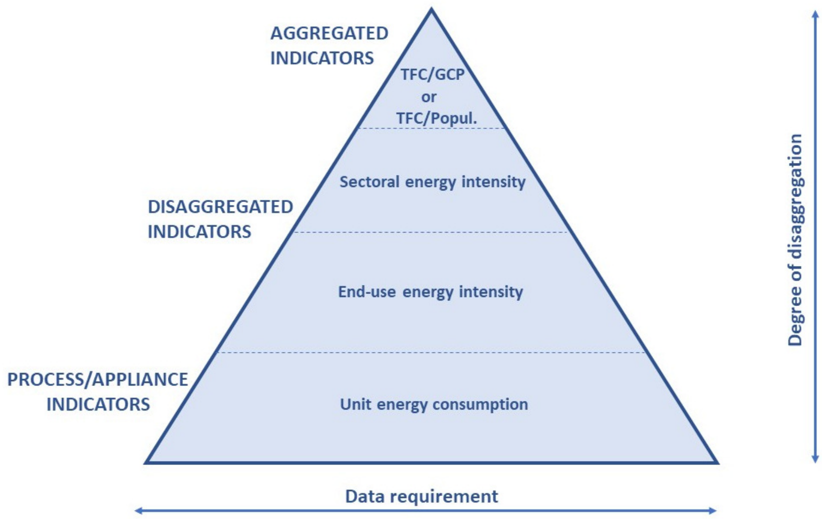

Figure 7. Energy end-use sectors framework (adapted from [18]*)*

The top row of the pyramid contains the most aggregated indicators like energy consumption by GCP and population. The second level, instead, contains more detailed information regarding energy consumption per unit of activity in each sector (e.g. for the residential sector, total energy consumption per floor area). Lower rows, finally, represent energy intensity by end-use for each sector - like residential energy consumption for heating purposes per floor area - and, in general, characterize end-use appliances for each sector (for example, residential energy consumption for heating purposes per square meter in dwellings equipped with heat pumps).

It has to be noted that, by using this approach, a lot of energy intensity indicators could be defined for the "end-use sectors" sub-domain; however, for the present work, only a subset has been developed, basing on the available data for the case study presented in chapter 3, and extended with additional indicators.

To build some of these, the decomposition analysis technique has been used. In general, decomposition analysis consists in quantifying the relative impact of different drivers on the variation of a certain target variable, by splitting the overall change of the target variable in more or less factors of variation which are considered worthwhile for deriving meaningful insights.

In the particular case of energy consumption, decomposition analysis is often carried out by distinguishing among three main components affecting energy consumption which are the aggregate activity, the sectoral structure and energy intensity (i.e. energy efficiency). For the present purpose, due to data unavailability, decomposition analysis is only used in tertiary and transport sector and the choice of decomposition factors is well detailed in chapter 3.

Concerning the decomposition technique itself, different methods, which consider the definition of indexes to examine changes, are available in literature. Decomposition can be done by assuming additive or multiplicative configuration (see *Table 4*) and/or different base year type to make comparisons with. The base year can be fixed or chained; in particular, the chaining method involves the year-by-year changing of base year (for every year the previous one is used as base), and it produces more accurate results [18].

Table 4. Possible configurations of decomposition analysis [17]

Additive (sum form)	**Multiplicative (product form)**
$\Delta E = \Delta E_{ACT} + \Delta E_{STR} + \Delta E_{INT} + E_{RSD}$	$\mathrm{R} = R_{ACT} \cdot R_{STR} \cdot R_{INT} \cdot R_{RSD}$
where ΔE [MWh] and R [-] represent change in energy consumption calculated as in *Table 5* or *6*, depending on the decomposition methodology	

The most used methodologies for decomposition analysis applied in the energy sector are Simple Laspeyres and LMDI I (Logarithmic Mean Divisia Index I) [26],[27],[28]. When choosing a method over another, the main criteria, besides data availability, are their ease in interpretation and the theoretical soundness. In the case of index decomposition analysis, in fact, major issues are related to the presence of a residual or interaction term which is generated due to interaction among the factors in decomposition and, can be tolerable only if relatively small. The main advantage of Simple Laspeyres method (*Table* 5) is that it is quite easy to be communicated but, on the other hand, this comes with the additional cost of generating a residual term. Decomposition analysis with LMDI I (*Table 6*), instead, is more difficult to communicate and to be carried out but it makes null the residual term.

Table 5. Simple Laspeyres index decomposition methodology [17]

	Additive	Multiplicative
Activity effect (ACT)	$\Delta E_{ACT} = A^T \cdot \sum_i S_i^0 \cdot I_i^0 - E^0$	$R_{ACT} = \frac{A^T \cdot \sum_i S_i^0 \cdot I_i^0}{E^0}$
Structure effect (STR)	$\Delta E_{STR} = A^0 \cdot \sum_i S_i^T \cdot I_i^0 - E^0$	$R_{STR} = \frac{A^0 \cdot \sum_i S_i^T \cdot I_i^0}{E^0}$
Intensity effect (INT)	$\Delta E_{INT} = A^0 \cdot \sum_i S_i^0 \cdot I_i^T - E^0$	$R_{INT} = \frac{A^0 \cdot \sum_i S_i^0 \cdot I_i^T}{E^0}$
being T the final year, 0 the base year, i the sub-sector or end-use, A the activity, S the structure, I the intensity, E the energy consumption [MWh]		

Table 6. LMDI I decomposition methodology [17]

	Additive	Multiplicative
Activity effect (ACT)	$\Delta E_{ACT} = \sum_i L(E_i^T, E_i^0) \cdot \ln\left(\frac{A^T}{A^0}\right)$	$R_{ACT} = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \cdot \ln\left(\frac{A^T}{A^0}\right)\right)$
Structure effect (STR)	$\Delta E_{STR} = \sum_i L(E_i^T, E_i^0) \cdot \ln\left(\frac{S_i^T}{S_i^0}\right)$	$R_{STR} = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \cdot \ln\left(\frac{S_i^T}{S_i^0}\right)\right)$
Intensity effect (INT)	$\Delta E_{INT} = \sum_i L(E_i^T, E_i^0) \cdot \ln\left(\frac{I_i^T}{I_i^0}\right)$	$R_{INT} = \exp \sum_i \left(\frac{L(E_i^T, E_i^0)}{L(E^T, E^0)} \cdot \ln\left(\frac{I_i^T}{I_i^0}\right)\right)$
where $L(a,b) = \frac{a-b}{lna-lnb}$		

For the analysis presented in chapter 3, it has been chosen to use LMDI I method, with additive configuration and chained base year.
The whole list of indicators developed for this sub-domain is then reported in the following, field by field. As stated before, it is mainly constituted by energy intensity indicators plus indicators regarding sectoral energy consumption obtained by means of decomposition analysis and other indicators of importance for each field.

- **Energy intensity by gross city product** EI_{GCP} **[MWh/k€] (ES/S-EC-EUs/We)** (adapted from [29])

$$EI_{GCP} = \frac{E_{tot}}{GCP} \tag{2.8}$$

where the gross city product GCP is calculated in k€ as the sum of the total income by taxpayers and E_{tot} is the total energy consumption as calculated with (2.5). EI_{GCP} represents a key indicator for both energy system and socio-economic domains.

- **Energy intensity by number of inhabitants (ES/S-EC-EUs/We)** EI_{Pop} **[MWh/inhab.]** [29]

$$EI_{Pop} = \frac{E_{tot}}{Pop} \tag{2.9}$$

where Pop is the total population of the municipality.

- **Energy intensity in tertiary sector (ES/S-EC-EUs/We-Te)** EIT **[MWh/€]** [18]

$$EIT = \frac{\sum_{j=1}^{n}(E_{t.j})}{\sum_{i=1}^{m} VA_{t,i}} \tag{2.10}$$

$VA_{T,i}$ represents the value added [M€] in the i-th tertiary activity class among the n tertiary activity classes as classified in 2.3, and j is the energy commodity among the m energy commodities used in the tertiary sector. This indicator relates the total energy consumption in the tertiary sector with the total value added generated, which can be considered a measure of the level of economic activity for the tertiary sector. Higher economic activity, in fact, is related to increases in commercial activity and stock of buildings, and to more people employed in the sector. These leads to an increased demand for energy services. It is worth to be noted that also other factors like age of buildings and floor area are responsible for variation in energy consumption even if, in this case, these phenomena are not taken into account due to the lack of data.

- **Variation of energy consumption in the tertiary sector due to activity/structure/intensity (ES/S-EC-EUs/We-T) [MWh]** [18]

For the evaluation of the change in energy consumption in the tertiary sector, it has been adopted the decomposition analysis approach assuming the economic activity (value added [M€]), the structure of the tertiary sector (measured as percentage of value added per activity class in the tertiary sector) and the energy intensity (calculated as the ratio between the energy consumption in the i-th activity class and the corresponding value added) as decomposition factors. To evaluate the variation for each of the three factors, the LMDI I equations presented above have been used. This set of indicators ($\Delta Et_{act}, \Delta Et_{str}, \Delta Et_{int}$) can be used to allocate changes in tertiary energy consumption and better explain the variation trend across years.

- **Climate-corrected energy intensity in residential sector by floor area (ES-EUs-Re) EIR_{RA} [MWh/m²]** [18]

EIR_{RA} evaluates the energy intensity in the residential sector as the ratio of the climate-corrected energy consumption and the total floor area of dwellings in the municipality. In particular, climate-corrected energy consumption allows for an adjustment to space heating consumption, normalizing the consumption pattern over time by removing the impact of year-to-year temperature variations. The advantage of using this indicator is that it allows one to take into account the effect of climate variations in trends of energy intensity with a unique figure. On the other hand, this indicator condense many phenomena and it should not be used for measuring energy efficiency developments. In fact, energy consumption in the residential sector is driven by many aspects like income level and growth, consumer preferences and behaviour, appliances and equipment penetration rate, number of occupied dwelling and inhabitants per household. EIR_{RA} is defined as:

$$EIR_{RA} = \frac{E_r^*}{RA} \tag{2.11}$$

where:

- RA is the total residential area [m²];
- E_r^* is the climate-corrected energy consumption [MWh] in residential sector calculated as:

$$E_r^* = \frac{E_r}{1 - \sigma_{heat} \cdot \left(1 - \tau_{heat,i}\right)} \tag{2.12}$$

- E_r is the total residential energy consumption [MWh];
- σ_{heat} [-] represents the elasticity[3]. The higher σ_{heat} is, the higher the impact of the correction to energy consumption values for climate effects.
- $\tau_{heat,i}$ is defined with:

[3] In economics, elasticity is a measure of a variable's sensitivity to a change in another variable. In this case it is used to modulate the impact of temperature variations across years with respect to climate-corrected energy consumption.

$$\tau_{heat,i} = \frac{DD_i}{\sum_{i=1}^{n} \frac{DD_i}{n}} \tag{2.13}$$

where DD_i represents the amount of degree days for the i-th year and n represents the number of years considered for the analysis. From (2.13) it can be observed that values of $\tau_{heat,i}$ higher than 1 occur if the amount of degree days for the i-th year is larger than the average value for the analysed timespan, implying a larger need for residential heating. In this case, the climate-corrected energy consumption in residential sector E_r^* will be lower than real energy consumption in residential sector E_r, capturing the effect of lower winter temperatures.

- **Climate-corrected energy intensity in residential sector by number of dwellings (ES-EUs-Re) [MWh/dwelling]** [18]

$$EIR_{DW} = \frac{\sum_{j=1}^{n} E_r^*}{DW} \tag{2.14}$$

The indicator evaluates the energy intensity in the residential sector as the ratio of the climate-corrected energy consumption [MWh] and the total number of occupied dwellings DW [-] in the municipality. While the previous indicator is more closely related to the final energy uses of heating and cooling, this one can be used to better address the type of use of lighting, water heating and appliances.

- **Percentage of residential buildings with low/medium/high envelope performances (winter/summer) (ES-EUs-Re)** $H_{env,i}$ [%]

This indicator $H_{env,i}$ - where i represents the quality of envelope performances (low/medium/high) - is used to evaluate the performance of residential buildings in terms of insulation. Insulation in residential buildings is fundamental to reduce energy consumption through improved energy conservation. In particular, insulation performances of residential buildings can be evaluated by the method proposed in "Allegato 1 - DL 26 giugno 2015" which promulgates national guidelines for buildings' energy labelling. The indicator scale is qualitative and, in the case of the evaluation of winter performance, it is based on the value of the thermal performance index for heating purposes $EP_{H,nd}$, compared with the limit value $EP_{H.nd,\lim\,(2019-21)}$, both calculated as specified in DL 26/06/2015 (see Table 7).

Table 7. Winter performance of buildings' envelope (DL 26/06/2015)

Winter performance of buildings' envelope	Quality
$EP_{H.nd} \leq 1 \cdot EP_{H.nd,\lim\,(2019-21)}$	High
$1 \cdot EP_{H.nd,\lim\,(2019-21)} < EP_{H.nd} \leq 1.7 \cdot EP_{H.nd,\lim\,(2019-21)}$	Medium
$EP_{H.nd} > 1.7 \cdot EP_{H.nd,\lim\,(2019-21)}$	Low

Concerning the summer performance of buildings' envelope, the parameters of interest are instead the equivalent solar surface area per unit of useful surface area $\frac{A_{sol,est}}{A_{sup,utile}}$ and the periodic thermal transmittance Y_{IE}, both calculated as specified in DL 26/06/2015. Table 8 shows the limit values for the two parameters.

Table 8. Summer performance of buildings' envelope (DL 26/06/2015)

Summer performance of buildings' envelope		**Quality**
$\frac{A_{sol,est}}{A_{sup,utile}} \leq 0.03$	$Y_{IE} \leq 0.14$	High
$\frac{A_{sol,est}}{A_{sup,utile}} \leq 0.03$	$Y_{IE} > 0.14$	Medium
$\frac{A_{sol,est}}{A_{sup,utile}} > 0.03$	$Y_{IE} \leq 0.14$	Medium
$\frac{A_{sol,est}}{A_{sup,utile}} > 0.03$	$Y_{IE} > 0.14$	Low

It should be noted that data needed to build this indicator are particularly scarce, but since they are part of APEs, their availability is expected to increase in the next years. In fact, the drafting of APE, the document containing the energy features of buildings which defines related energy performances, is mandatory in case of building selling and renting, as well as for new buildings and for repurposing which affect more than 25% of the building itself.

- **Percentage of residential buildings by heating systems typology/energy carrier H_{hpl} [%] (ES-EUs-Re)**

$$H_{hpl} = \frac{H_{hpl.i}}{H_{tot}} \cdot 100 \qquad (2.15)$$

The indicator is calculated as the ratio between the number of buildings equipped with heating system i (or, alternatively, fuelled with the i-th energy commodity) $H_{hpl.i}$ and the total number of residential buildings H_{tot}. It allows for the monitoring and analysis of residential-based heating plants which is a topic of main importance, especially in municipalities characterized by cold and long winters, in terms of energy efficiency, greenhouse gas emissions and local atmospheric pollution. Again, data needed to build this indicator are particularly scarce.

- **Energy intensity in transport sector by class of vehicle and fuel $EIT_{i,j}$ $\left[\frac{MWh}{Mpkm}\right]$ (ES-EUs-Tr)** (adapted from [18])

$$EIT_{i,j} = \frac{E_{tr,i,j}}{Pd_{i,j}} \qquad (2.16)$$

In the context of municipalities, the analysis of the transport sector should be focused on the evaluation of the passenger transport which represents most of the energy consumption. Energy consumption in the passenger transport sector is driven by many factors like vehicle ownership rates, vehicle occupancy rates, age and type of vehicle, travel patterns, consumer preference, transport infrastructure and land use sprawl [18]. The most refined parameter used to evaluate energy intensity in the passenger transport sector is the distance travelled per number of passengers (passenger distance) and measured in pkm, which represents the transport of one passenger over one kilometer. The big advantage of using this parameter to calculate energy intensity is that it allows for meaningful comparisons between different classes of vehicles (e.g. bus vs car) by weighting the energy consumption with the distance travelled by passengers. On the other hand, data about passenger distance are very difficult to be retrieved and are often the outcome of approximations.
Theoretically, one could define the energy intensity in transport sector by class of vehicle (bus, metro, tram, car, motorcycles, urban train…) and by fuel (gasoline, diesel oil, electricity, LPG, compressed natural gas, hydrogen) with (2.16) where $E_{tr,i,j}$ and $Pd_{i,j}$ are respectively the energy consumption [MWh] and the passenger distance [Mpkm] by class of vehicle i (among the m typologies of vehicles in the municipality) and fuel j (among the n typologies of fuels used in transport sector in the municipality). Then, by considering a certain class of vehicle i, and summing up respectively energy consumption and passenger distance over all n fuel typologies, energy intensity by vehicle class i EIT_i can be obtained. Finally, summing up respectively energy consumption and passenger distance over all m classes of vehicles and n fuel typologies, and performing the ratio of the two values, energy intensity in transport sector EIT is obtained.

- **Energy intensity in transport sector, by vehicle class i** EIT_i $\left[\frac{MWh}{Mpkm}\right]$ **(ES-EUs-Tr)** [18]

$$EIT_i = \frac{\sum_{j=1}^{n} E_{tr,i,j}}{\sum_{j=1}^{n} Pd_{i,j}} \qquad (2.17)$$

- **Energy intensity in transport sector** EIT $\left[\frac{MWh}{Mpkm}\right]$**(ES-EUs-Tr)** [18]

$$EIT = \frac{E_{tr}}{Pd} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} E_{tr,i,j}}{\sum_{i=1}^{m}\sum_{j=1}^{n} Pd_{i,j}} \qquad (2.18)$$

being E_{tr} the total energy consumption in the transport sector [MWh] and Pd the total per passenger-distance travelled [Mpkm].

Supporting indicators regarding energy intensity in public and private transport sectors can be easily obtained by aggregation of (2.17).

- **Percentage of cars by EURO classification (ES/En-EUs/Em-Tr/AP)** Car_{euro} [%]

$$Car_{euro} = \frac{Car_{E,j}}{\sum_{j=1}^{n} Car_{E,j}} \cdot 100 \qquad (2.19)$$

where $Car_{E,j}$ is the number of cars [-] with j-th EURO classification among the n =6 EURO classes (from EURO1 to EURO6).
This indicator is a cross-sectoral one, since it can be used to monitor the evolution of municipal car fleet in terms of impact on air pollution, regulated through the European Emission Standards.

- **Energy consumption per number of public spot lighting (ES-EUs-O)** $EIPl$ $[MWh]$

$$EIPl = \frac{E_{pl}}{PL_{tot}} \qquad (2.20)$$

The indicator correlates the trend in energy consumption for public lighting E_{pl} [MWh] with the total number of public spot lighting PL_{tot} [-]. It can be used to better understand if reduction in energy consumption is driven by progress in public lighting efficiency (e.g. installation of LED/smart lamps) or by a reduction in public lighting activity, whose PL_{tot} is a proxy variable.

- **Percentage of LED lamps per number of public spot lighting (ES-EUs-O)** $PL_{LED\%}$ [%]

$$PL_{LED\%} = \frac{PL_{LED}}{PL_{tot}} \cdot 100 \qquad (2.21)$$

where PL_{LED} represents the amount of LED lamps used in public lighting. The indicator is a measure of efficiency in public lighting.

- **Energy intensity in solid waste management (ES/En-EUs/Re-O/W)** $\left[\frac{MWh}{ton_{waste}}\right]$

$$EIW = \frac{E_{waste}}{W_{S,nh} + W_{S,h} + W_U} \qquad (2.22)$$

The indicator is calculated as the ratio between the total energy consumption during waste treatment E_{waste} [MWh] and the total amount of treated waste which is the sum of non-hazardous special waste $W_{S,nh}$, hazardous special waste $W_{S,h}$ and municipal waste W_U [ton]. The evaluation of E_{waste} is particularly complex since it involves the calculus of energy consumption during the phases of garbage collection, transportation, and final disposal. Furthermore, the energy consumption in buildings designated to waste management should also be included, since it is not accounted for in the tertiary sector. On the other hand, data regarding total amount of municipal and special waste should be easily available.

- **Energy intensity in wastewater management (ES/En-EUs/Re-O/Wat)** $EIWat\ \left[\frac{MWh}{eq.inhab.}\right]$

$$EIWat = \frac{E_{wat,consumed}}{Pop_{eq}} \qquad (2.23)$$

The energy intensity in water management is calculated as the ratio between the total energy consumption in water management $E_{wat,consumed}$ [MWh] and the number of equivalent inhabitants Pop_{eq} [eq.inhab]. The former is evaluated as the sum of energy consumption in the phases of water supply and wastewater collection and depuration, while the latter is a measure of water pollution, being the equivalent inhabitant defined as the pollution load immitted in wastewater from an inhabitant permanently resident during a day (60g BOD_5/day).

2.5.4 Environment – Resources

Indicators developed for the subdomain "Resources" aim to judge performances in the management of water, waste and land use which are key areas in urban development. It has to be noted that no dedicated indicators have been built for the field of "Renewable resources" which, even if important to understand the potentialities of renewable energy production in the municipality, it is not characterized by phenomena which substantially change in time; for example, the availability of solar/wind resources mainly depends by the analyzed area and it is not particularly significative to track its year-to-year variations.
Regarding the *water* field, the developed set of indicators aim to consider the most relevant aspects of the water cycle at urban level (*Figure 8*). In the following, the main phases of urban water cycle and correlated indicators are presented.

1. **Supply**: the range of activities regarding the provision and pre-treatment of water which aim to supply citizens with a high-quality resource. Indicators are focused on the evaluation of water quality.

- **Compliance with quality standards for water supply (En-Re-Wat)** [%]
  The indicator $Wa_{,qual}$ shows the percentage of compliant parameters with limit values provided by DL 31/2001 regarding the features of water quality for human use.
- **Number of verified parameters per inhabitant (En-Re-Wat)** [-]
  The indicator $Wa_{,par}$ shows the number of analysed parameters related to water quality (pH, conductivity…) per inhabitant.

2. **Distribution**: in this phase water is transported to the final users by means of aqueducts; the main figure of merit in this case is:

- **Percentage of water distribution losses in aqueduct (En-Re-Wat)** [%]
  The indicator $Wa_{distr,loss}$ evaluates the percentage of water losses due to worn-out pipes and/or illegal withdrawal.

3. **Final use**. Indicators for this phase are related to trends in water consumption in the municipality.

- **Average daily consumption of water by inhabitant (En-Re-Wat)** $\bar{W}$ **[l/ab·day]**

$$\bar{W} = \frac{W_{consumed}}{Pop \cdot 365} \qquad (2.24)$$

where $W_{consumed}$ is the yearly consumption of water [l] and Pop the number of inhabitants.

4. **Wastewater collection**: wastewater produced by domestic and industrial activities are sent to specific treatment centres by means of drainage system.
5. **Wastewater disposal**: wastewater is depurated and treated in order to reuse and/or reinsert it into water bodies without damaging the surrounding ecosystem. Two indicators are used to analyze this phase:

- **Percentage of population served by wastewater treatment systems** $Wa_{tr,pop}$ **(En-Re-Wat)** [%]
- **Compliance with quality standards for water discharge** CWD_i [%] **(En-Re-Wat)**

The indicator describes compliance of the parameters BOD_5 (biodegradable organic compounds), COD (organic compounds), SST (total suspended solids), P (phosphorus), N (nitrogen) with limit values provided by DL 152/200 which regulates the characteristics of water quality for urban wastewater treatment plants. In particular:

- BOD_5 and COD are used to measure the quantity of organic matter contained in wastewater. The former represents the amount of oxygen demanded by micro-organisms for the decomposition of bio-degradable matter in wastewater under 5 days of aerobic conditions at 20 °C, whereas the latter is the amount of oxygen that is required for the chemical oxidation of the organic and inorganic chemicals present in the wastewater by utilizing oxidizing agents, and it is used to measure both biodegradable and non-biodegradable organic matter.
- SST are the total suspended solids, categorized as waterborne particles that exceed 2 microns in size, mainly inorganic compounds.
- The amount of P and N should be contained to avoid water eutrophication - the excessive spread of nutritive substances in water causing the rise of vegetal organisms - in waterways and near coasts.

Compliance with water discharge is evaluated for each parameter with:

$$CWD_i = \frac{\eta_{wa,tr_i}}{L_i} \qquad (2.25)$$

where η_{wa,tr_i} represents the removal efficiency [%] of the i-th pollutant for the municipal wastewater treatment plant and L_i the limit value [%].

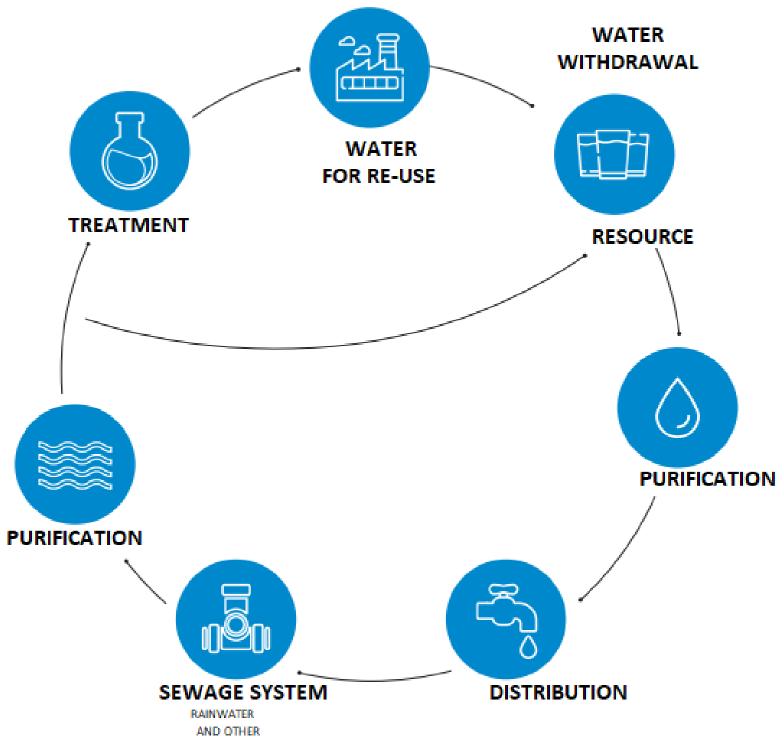

Figure 8. Urban water cycle (adapted from [30]*)*

Furthermore, additional, cross-sectoral indicators have also been defined to consider possible relationship with other fields of the urban framework. These are:

- **Percentage of recycled non-hazardous waste in water integrated service** $\eta_{water,nhw}$ **[%] (En-Re-Wat/W)**

$$\eta_{water,nhw} = \frac{NHW_{rec}}{NHW} \tag{2.26}$$

where NHW_{rec} and NHW are respectively the recycled fraction and the total amount of non-hazardous waste [ton]. Given that non-hazardous waste usually represents the most ($\approx 99\%$) of the waste produced by the water integrated service, the amount of recycled waste for this category is significative to evaluate sustainability in water-related waste disposal.

- **GHG emissions per equivalent inhabitant in water integrated service** GHG_{water} **[tCO2eq/eq.inhab.] (En-Re/Em-Wat/GHG)**

$$GHG_{water} = \sum_{i=1}^{n} \frac{GHG_{wa,i}}{Pop_{eq}} \tag{2.27}$$

GHG_{water} is used to evaluate the global greenhouse gas emissions in water integrated cycle, as the ratio between the sum of all GHG emissions sources in water integrated cycle [tCO2eq] and the equivalent number of inhabitants Pop_{eq} [eq.inhab.]. Peculiar GHG emissions sources regard process emissions which are related to water biological treatment, anaerobic digestion and denitrification of sludges, and potable water ozonation.

- **Atmospheric pollutant emission per inhabitant in water integrated service** $AP_{water,i}$ **[ton$_{pol}$/eq.inhab.] (En-Re/ Em- Wat/AP)**

$$AP_{water,i} = \frac{m_{pol,wa_i}}{Pop_{eq}} \tag{2.28}$$

The indicator is calculated as the ratio between the mass of i-th air pollutant m_{pol,wa_i} (CO, NMVOC, fine dust, NO_X, SO_X, NH_3) [ton] produced in urban water cycle and the number of equivalent inhabitants Pop_{eq}. Atmospheric pollutant emissions are mainly related to the process of chemical scrubbing used for water deodorization, water biological treatment, natural gas combustion and discharge of water in water bodies.

Concerning the *waste* field, a similar approach to the one used for developing water indicators has been used, analyzing the waste chain (generation, collection, disposal, recycling and treatment) and integrating the defined set with indicators from [31].

In general, waste can be classified in typologies as in the European List of Wastes (LoW) [32], which defines 839 waste types structured into 20 chapters, according to the source of the waste (i.e. the economic sector or process of origin); waste are further categorized by means of a six-digit code. Furthermore, the various waste types can be aggregated in classes as special hazardous waste, special non-hazardous waste and urban waste as specifically defined by DL 152/2006. To give a rough idea of the various classes, urban wastes includes the ones produced in civil residence and from street sweeping and green areas, whereas special waste are the ones generated from agriculture, industrial, commercial and manufacturing activities, and services. In the following, indicators have been constructed focusing on the management of urban waste only, since the tracking of special waste disposal processes is quite constrained by data unavailability (see chapter 3) and, also, they are usually managed at regional instead that municipal level.

- **Urban waste generation per capita W_U $[\frac{kg \cdot year}{inhab.}]$ (En-Re-W)**

Urban waste generation per capita W_U accounts for the yearly generated waste per number of inhabitants as calculated with ISPRA methodology. This considers as urban waste the sum of urban undifferentiated waste and differentiated waste as reported in *Table 9*. Codes in brackets refer to the typology as classified in the European List of Wastes.

Table 9. Urban waste classification (adapted from [33]*)*

Waste class	Waste fraction
Urban undifferentiated waste	• Urban undifferentiated waste (200301) • Waste from streets sweeping intended for disposal (200303) • Other undifferentiated urban waste (200399) • Bulky waste mixed with disposed waste (200307)
Urban differentiated waste	• Biodegradable fraction (wet fraction and green waste) • Packaging waste, paper, plastic, wood, metal, and glass from chapter 20 of LoW • Bulky waste mixed with recycling waste (200307) • Textile waste • Selective waste (drugs, batteries, vegetal oils, ecc.) • DEEE • C&D waste (only 170107 and 170904 related to small demolition operations) • Sweeping waste (200303) for separate collection

	• Other waste fractions separately collected

- **Recycling rate of solid waste $W_{U,rec}$ [%] (En-Re-W)**

The recycling rate of solid waste $W_{U,rec}$ is calculated as the ratio between differentiated and total urban waste, defined as above.

- **Expenditure on urban waste management per capita WC_U [€/(*inhab.*)] (En/S-EC-Re/We-W)**

The indicator WC_U shows the yearly expenditure per capita for urban waste management. Total cost is calculated by following ISPRA methodology and takes into account cost items reported in *Table 10.*

Table 10. Cost items for urban waste management [33]

Cost item	Components
Costs for management of undifferentiated waste *CGIND*	• Sweeping and cleaning of streets (CSL) • Collection and transport (CRT) • Treatment and disposal (CTS) • Other
Communal costs *CC*	• Administrative costs (CARC) • Management (CGG) • Other (CCD)
Capital use costs *CK*	• Amortisation of mechanical vehicles for collection, vehicles and equipment for sweeping, waste containers and other amortisations (AMM) • Funds (ACC) • Capital remuneration (R)
Costs for management of differentiated waste *CGD*	• Differentiated collection of single materials (CRD) • Treatment and recycle (CTR), net of revenues from material selling, recovered energy and CONAI subsidies

- **Special waste generation per capita W_S $[\frac{kg \cdot year}{inhab.}]$ (En-Re-W)**

Special waste generation per capita W_S defines the yearly production of special waste per inhabitant.

- **Gross energy generation per quantity of treated waste WEG [$\frac{MWh}{ton}$] (En-Re-W)**

$$WEG = \frac{EP_{waste}}{W_{tr}} \tag{2.29}$$

where EP_{waste} is the gross energy (both thermal and electric) generated from waste treatment [MWh] and W_{tr} is the quantity of treated waste calculated as the sum of urban and special waste [ton]. To evaluate this indicator, all the energy production facilities (like waste incineration plants) using waste as fuel must be taken into account.

- **Number of exceedances of limits for atmospheric/water pollution in waste disposal process $APlim_{waste}$, $Watlim_{waste}$ [-] (En-Re/Em-W/AP/Wa)**

The indicators $APlim_{waste}$ and $Watlim_{waste}$ accounts for the number of notifications of non-compliance with environmental legislation regarding air/water pollution. Indicator should be evaluated at least for the main waste disposal facilities of the municipality.

- **GHG emissions per quantity of treated waste GHG_{waste} [$\frac{t_{CO2,eq}}{t_{waste}}$] (En-Re/Em-W/GHG)**

$$GHG_{waste} = \frac{GHG_{waste,tot}}{W_{tr}} \tag{2.30}$$

GHG emissions ($GHG_{waste,tot}$) in the process of waste management arise from the process of waste collection and transportation (mainly due to waste-carrying vehicles), from waste disposal in landfills (due to gas releases), energy generation facilities (due to natural gas burning) and waste recovery plants, and due to energy consumption in related buildings. Again, calculating this indicator could be particularly difficult due to the complexity in tracking waste routes from collection to final disposal; the evaluation should then be focused on emissions generated from waste management facilities (vehicles and buildings) inside the municipal territory, and waste disposal facilities which treat the most of generated waste.

Indicators developed for the *"land use"* field are used to describe and show trends regarding the division of municipal land. In general, use of land for different purposes in cities changes quite slowly and to perceive significant changes it is needed monitoring periods of at least several decades [34]. Since the theme of urban planning is outside the scope of this thesis, for the present analysis, relevance is given to the evaluation of a restricted set of indicators regarding share of built-up areas and related density, green spaces, pedestrian areas and bike roads. Meaningful indicators are reported in the following.

- **Consumed soil per capita** CS_{cap} $[\frac{ha}{100.000ab}]$ **(En-Re-LU)**

$$CS_{cap} = \frac{CS}{Pop} \tag{2.31}$$

Consumed soil per capita is evaluated as the ratio between the amount of consumed soil CS [ha] and the number of inhabitants Pop. Change in consumed soil is defined as the variation from non-artificial coverage of the soil (not consumed soil) and artificial coverage of the soil (consumed soil) [35].

- **Green surface per capita** GS_{cap} $[\frac{ha}{100,000in}]$ **(En-Re-LU)**

$$GS_{cap} = \frac{GS}{Pop} \tag{2.32}$$

Green surface per capita is evaluated as the ratio of green surface GS [ha] and the number of inhabitants Pop [100,000 inhab.]. Green surface includes equipped green areas, green street furniture, urban forestation, scholastic gardens, botanical gardens, zoo gardens, graveyards, sport areas, and woodland areas.

- **Urban dispersion index** UDI [-] **(En-Re-LU)**

The urban dispersion index is yearly calculated by ISPRA and it is defined as the ratio between the extension of average/low density areas (sub-urban areas) and the total amount of both high density (urban) areas and average/low density (sub-urban) areas. High values of the indicator are obtained for cities with prevalence of low-density areas while low values identify compact cities. In general, high levels of dispersion are related to negative performances in land management, like reduction of green areas, soil consumption and higher probability of citizens using means of transport to reach workplace.

- **Pedestrian area per 100 inhabitants** PA_{POP} $[\frac{m^2}{100inhab.}]$ **(En/ES-Re/FU-LU/Tr)**

Pedestrian areas are fundamental to incentive pedestrian traffic and can reduce the level of air pollution and noise due to vehicular traffic in high-density urban areas.

- **Bike roads density** BRD $[\frac{km}{100km^2}]$ **(En/ES-Re/FU-LU/Tr)**

A higher level of the indicator means a better interconnection among municipality areas, and it is then related to a higher probability of citizens moving with bikes in the municipality, reducing vehicular traffic.

2.5.5 Environment - Emissions

The "Emissions" sub-domain is used to track level of both air pollution and greenhouse gases emissions in the municipal context.
Sources of local air pollution are mainly mobile sources, like cars and buses, and stationary sources, like residential boilers, power plants and industrial facilities. However, air pollution in cities also depend by climate effects and city's geography: if wind and rain are fundamental drivers in transporting and/or reducing air pollutants' level, the geographical position of the city and the morphology of the surrounding territory also play an important role. Meaningful indicators, then, should be focused on the evaluation of trends of concentration of air pollutants in the air, comparing their average value with standard limits. In particular, the EU's air quality directives (2008/50/EC Directive on Ambient Air Quality and Cleaner Air for Europe and 2004/107/EC Directive on heavy metals and polycyclic aromatic hydrocarbons in ambient air) set pollutant concentration thresholds that shall not be exceeded in a given period of time, while WHO values set for the protection of the health are even stricter than EU standards. Limit values for main air pollutants are reported in *Figure 9* .

		EU Air Quality Directives			WHO Air Quality Guidelines					
Pollutant	Averaging period	Objective	Concentration	Comments	Concentration					Comments
					Interim targets 1.	2.	3.	4.	AQG level	
$PM_{2.5}$	24-hour	Target value			75	50	37,5	25	15 μg/m³	99th percentile (i.e. 3–4 exc. Days/year)
$PM_{2.5}$	Annual	Limit value	25 μg/m³		35	25	15	10	5 μg/m³	
$PM_{2.5}$	Annual	Indicative limit value	20 μg/m³							
PM_{10}	24-hour	Limit value	50 μg/m³	Not to be exceeded on more than 35 days/year	150	100	75	50	45 μg/m³	99th percentile (i.e. 3–4 exc. Days/year)
PM_{10}	Annual	Limit value	40 μg/m³		70	50	30	20	15 μg/m³	
O_3	Max. daily 8-hour mean	Target value	120 μg/m³	Not to be exceeded on more than 25 days/year (averaged over 3 years)						
O_3	Max. daily 8-hour mean	Long-term objective	120 μg/m3							
O_3	8-hour	Target value			160	120	–	–	100 μg/m³	99th percentile (i.e. 3–4 exc. Days/year)
O_3	Peak season [a]	Target value			100	70	–	–	60 μg/m³	
NO_2	Hourly	Limit value	200 μg/m³	Not to be exceeded on more than 18 hours/year					200 μg/m³	
NO_2	Annual	Limit value	40 μg/m³		40	30	20	–	10 μg/m³	
NO_2	24-hour	Target value			120	50	–	–	25 μg/m³	99th percentile (i.e. 3–4 exc. Days/year)
SO_2	Hourly	Limit value	350 μg/m³	Not to be exceeded on more than 24 hours/year						
SO_2	24-hour	Limit value	125 μg/m³	Not to be exceeded on more than 3 days/year	125	50	–	–	40 μg/m³	99th percentile (i.e. 3–4 exc. Days/year)
CO	Max. daily 8-hour mean	Limit value	10 mg/m³						10 mg/m³	
CO	24-hour	Target value			7	–	–	–	4 mg/m³	99th percentile (i.e. 3–4 exc. Days/year)
C_6H_6	Annual	Limit value	5 μg/m³						1,7 μg/m³	Reference level
BaP	Annual	Target value	1 ng/m³	Measured as content in PM_{10}						
Pb	Annual	Limit value	0,5 μg/m³	Measured as content in PM_{10}					0,5 μg/m³	
As	Annual	Target value	6 ng/m³	Measured as content in PM_{10}					6,6 ng/m³	Reference level
Cd	Annual	Target value	5 ng/m³	Measured as content in PM_{10}					5 ng/m³	
Ni	Annual	Target value	20 ng/m³	Measured as content in PM_{10}					25 ng/m³	Reference level

Figure 9. Air quality limit values (from [36]*).*

In the present work, the analysis has been restricted to NO_2 and PM_{10}; the reasons for that are mainly data unavailability and/or low level of air pollutants' concentration for the analysed case study, if compared with EU limit values. Selected indicators are then:

- **PM_{10} yearly average concentration** API_{PM10}^{ya} $[\mu g/m^3]$
- **Number of hourly average exceedances for PM_{10} limits** API_{PM10}^{hae} [-]
- **NO_2 yearly average concentration** API_{No2}^{ya} $[\mu g/m^3]$

The calculation of the previous indicators should be made basing on data from background stations instead of traffic and industrial stations. Measurements from background stations, in fact, are not directly influenced by individual sources of air pollution but take into account the integrated contribution of all the various sources. Furthermore, given that more than one measurement station is usually present in large cities, the indicator should be evaluated as the average of average concentration by station.
Concerning GHG emissions, instead, indicators should focus, first of all, on the total amount of GHG emissions produced in the municipality and, secondly, on the analysis of the principal causes of GHG emissions in the city. For the first purpose, the following indicator has been developed.

- **Global greenhouse gases emissions (En-Re-GHG)** [t_{CO2eq}]

$$GHG_{tot} = \sum_{i=1}^{n} GHG_i \tag{2.33}$$

Global greenhouse gases emissions GHG_{tot} is defined as the sum of GHG emissions (measured in t_{CO2eq}) from all the *n* GHG sources (GHG_i) in the municipal context. To correctly calculate this indicator, it is fundamental to preliminary define which types of gases, scopes, and sectors are taken into consideration. This choice depends on the broader topic of urban climate neutrality for which, however, there is currently not a unique definition. For this work, it has been decided to stick to the indications provided by [37], assuming it will represent the reference paradigm for European cities in the next years. This defines as target GHGs (expressed as CO_2 equivalents) the following ones: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). If emissions from the IPPU (Industrial Process and Product Use) are present, cities also have to cover emissions of hydro fluoro carbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Concerning the sectors/sources of emissions, instead, it has to be taken into account:

- Emissions from stationary energy: emissions from combustion of fossil fuels in all buildings and facilities. This includes residential, commercial, municipal and industrial buildings as well as public lighting within the administrative city boundary.
- Emissions from the consumption of electricity and district heating/cooling within the city's boundary, from power plants located within or outside the city boundary, quantified by means of local emission factors.
- Emissions from combustion of fossil fuels for all vehicles and transport within the city boundary.
- Emissions arising from waste (both solid waste and wastewater) generated within the city boundary, treated/managed/disposed within or outside the city boundary.

- Emissions from changes in land use including agriculture, forestry and other land uses (collectively referred to as 'AFOLU') within the city boundary.
- Emissions from chemical processes in industry (collectively referred to as Industrial Process and Product Use or 'IPPU') within the city boundary.

Further specifications regard emissions from any large-scale energy generation or industrial facilities, biomass and CCS (carbon capture and storage systems). In particular, plants located within the city boundary which are registered under the EU Emission Trading Scheme (EU ETS) should not be accounted for, given that municipalities have very limited influence over their operation, whereas emissions from biomass can be considered null only if sustainability criteria are respected[4]. Furthermore, the contribute to GHG emission reduction of the potential CCS systems installed within the municipality boundaries are taken into account only in case of permanent sequestration of CO_2.
Finally, concerning GHG scopes, only scope 1 (direct) and scope 2 (indirect) emissions need to be accounted for; in particular, scope 1 emissions are those arising from buildings, facilities, industry, transport, waste treatment, agriculture and forestry located inside the geographic boundary of the city, whereas scope 2 emissions are referred to consumption of grid-supplied electricity and grid-supplied heat or cold within the geographic boundary of the city. The only extension to the above-mentioned rules is related to the scope 3, namely emission arising from the energy consumption of waste and wastewater treatment plants and/or disposal facilities which, even if placed outside the geographical boundary of the municipality, must be accounted for.
Another meaningful indicator used to evaluate the contribution of each end-use sector on global greenhouse gases emissions is the following:

- **Greenhouse gases emissions intensity by sector (En-Re-GHG)** [-]

$$GHG_{sect,j} = \sum_{i=1}^{n} \frac{GHG_{j,i}}{GHG_{tot}} \qquad (2.34)$$

where $GHG_{j,i}$ represents GHG emissions from the j-th end-use sector and i-th energy commodity among the n energy commodities used in the municipality.

Once global GHGs emissions have been accounted for, it is necessary to understand what factors are the most relevant, to reduce their relative impact. In particular, reduction of GHG

[4] Biomass energy is associated with zero emissions only if the net gains are equal or superior to the net losses, meaning that the CO2 emissions to the atmosphere due to the end-user consumption are entirely compensated by the CO2 removal on the productive land, and that this has been certified (Article 29 of the Directive EU 2018/2001)

emissions can be realised by either reducing energy consumption or changing fuel mix; whereas the first strategy requires global improvements of energy efficiency, the second one consists in satisfying the same end-use by switching to low-carbon emission fuels also known as decarbonisation of end-use sectors.

To consider the relative effect of the two strategies on the global amount of greenhouse gases emissions, decomposition analysis can be used. The same approach used before (decomposition in additive form, chained years) is proposed, but in this case, *activity* represents final energy consumption ([MWh]), *structure* is the percentage of final energy consumption by energy carrier ([%]), and *intensity* represents the emission factor of the energy carriers ([tCO_2/MWh]). Consequently, one can evaluate the effect of reducing energy consumption by looking at variation in activity (ΔGHG_{Energy}), and the effect of fuel mix switching by looking at variation in structure ($\Delta GHG_{fuelmix}$).

Furthermore, variation in intensity can also be considered to evaluate the effect of changes in the value of emission factors (ΔGHG_{EF}) for electricity and district heating/cooling. In fact, even if emission factors of most energy commodities are fixed, emission factors of electricity and district heating/cooling depend on the primary energy sources they are produced with; power production from PV plants emits less GHGs than power production from natural gas. In computing GHG emissions balances, this effect must be considered by means of proper emission factor. For this study, "standard" emission factors, as defined by (IPCC,2006), and local electricity and district heating emission factors, defined in [38], have been used. In particular, local electricity emission factor $EFE\ \left[\frac{t_{CO_2}}{MWh_e}\right]$ is calculated as:

$$EFE = \frac{(TCE - LPE - GEP) \cdot NEEFE + CO_2LPE + CO_2GEP}{TCE} \qquad (2.35)$$

where TCE is the total electricity consumption within the city boundary $[MWH_e]$, LPE is the local production of electricity $[MWH_e]$, GEP represents the amount of green electricity purchased by local authority $[MWH_e]$, $NEEFE$ is the national emission factor for electricity $\left[t_{CO_2}/MWh_e\right]$, CO_2LPE is the total amount of carbon dioxide emissions due to local production of electricity $\left[t_{CO_2}\right]$ and CO_2GEP is the total amount of carbon dioxide emissions $\left[t_{CO_2}\right]$ due to production of green electricity purchased by local authority.

Instead, emission factor for district heating should be calculated by

$$EFH = \frac{(CO_2LPH + CO_2IH - CO_2EH)}{LHC} \qquad (2.36)$$

where EFH is the emission factor for district heating $[\frac{t}{MWht}]$, CO_2LPH represents the CO_2 emissions due to local production of heat $[t_{CO_2}]$, CO_2IH represents CO_2 emissions related to any imported heat from outside the territory of the local authority $[t_{CO_2}]$, CO_2EH represents

CO_2 emissions related to any heat that is exported outside of the territory of the local authority [t_{CO_2}] and LHC is the local consumption of heat [MWh_t]. Summarizing, the three indicators output of decomposition analysis are the following ones:

- **Variation of greenhouse gases emissions due to energy consumption/ fuel mix/ emission factor [tCO2eq] (En/Es-Re/FU-GHG)**

$$\Delta GHG_{Energy}$$
$$\Delta GHG_{fuelmix}$$
$$\Delta GHG_{EF}$$

2.5.6 Socio-economy – Wealth

The process of development of indicators in the socio-economy domain has been carried out by focusing the attention on the possible inter-relations with the theme of energy transition and by evaluating the impact of environmental damages on society.
In particular, *wealth* subdomain is used to analyse households' energy accessibility ("Energy Poverty" field), as well as trends in energy and environmental economy in the city ("Jobs and Value added" and "Investments" fields).
The *energy poverty* field is used to analyse the capacity of households of buying a minimum basket of goods and energy services needed for sake of minimum comfort and well-being. Furthermore, the theme is of primary importance also for possible consequences on health. For example, the absence of adequate heating in residences increases the probability of respiratory and cardiovascular diseases with the chance of an increase in deaths during winter, especially in colder climates; in United Kingdom it has been estimated that the reduction of one temperature degree in houses with respect to optimal values causes 3500 deaths in a year [39]. In Italy the definition of energy poverty is strongly correlated with the one of energy vulnerability that represents the condition for which access to energy services produces an expense larger than the socially acceptable one. In literature, given the vagueness of the previous definition, various indicators are available to analyse the phenomenon of energy poverty. However, in this work, indicators η_2 and η_3 proposed in [39], and used to evaluate energy poverty trends at national level, have been chosen.

- **Energy poverty $EP\eta_2$ [%] (S/EC-We-EP)** [39]

$EP\eta_2$ indicator defines the percentage of households living in energy poverty, where energy poverty is defined as the contemporary occurrence of two events:

a. a too large incidence of energy expense, compared with the double of yearly average value;
b. the circumstance that subtracting energy expense from total expense implicates for the family a net expense lower than the relative poverty line

EP_{η_2} is then defined as:

$$EP_{\eta_2} = \frac{100}{n_{fam}} \sum_{i=1}^{n} w_i \left\{ I \left[\frac{s_{ie}^{eq}}{s_i^{eq}} > 2 \cdot \left(\frac{\sum_{i=1}^{n} s_{ie}^{eq}}{\sum_{i=1}^{n} s_i^{eq}} \right) \right] \cdot I\left[(s_i - s_{ie}) < s_j^* \right] \right\} \tag{2.37}$$

where n_{fam} is the number of families considered for the analysis, w_i is the weight (i.e. the number of families represented) of the sample family unit i[5], s_{ie} (s_{ie}^{eq}) is the (equivalent) energy expense of the i-th family unit, $s_i(s_i^{eq})$ is the (equivalent) total expense of the i-th family unit, s_j^* is the relative poverty line in the analysed territory (being j the number of family members) and *n* represents the total number of sample unities in the survey. Equivalent expense is obtained by dividing the expense by the square root of the number of family members, whereas the relative poverty line, which depends on the number of family members, is defined by means of correction coefficients (Carbonaro coefficients) as specified in *Table 11.* In particular, correction coefficients are applied to the value of s_2^*, which defines the poverty line for a two-members family as the average expense in the analysed territory (obtained dividing total expense of the families by the total number of components).

Table 11. Poverty line

Number of family members	Poverty line
1	$s_1^* = s_2^* \cdot 0.60$
2	$s_2^* = \frac{\sum_{i=1}^{n} s_i}{\sum_{i=1}^{n} n_{comp_i}}$
3	$s_3^* = s_2^* \cdot 1.33$
4	$s_4^* = s_2^* \cdot 1.63$
5	$s_5^* = s_2^* \cdot 1.90$
6	$s_6^* = s_2^* \cdot 2.16$
7	$s_7^* = s_2^* \cdot 2.40$

- **Energy poverty EP_{η_3} [%] (S/EC-We-EP)** [39]

This indicator enlarges the former one by also considering as families living in energy poverty the ones with null heating expense (s_i^r) and equivalent expense lower than the median value of the analysed territory.

[5] In large statistical analysis carried out by ISTAT, given the large amount of examined unities and the impossibility of reporting related information, sample units are defined to simplify data delivering.

$$EP_{\eta_3} = \frac{100}{n_{fam}} \sum_{i=1}^{n} w_i \left\{ I\left[\frac{s_{ie}^{eq}}{s_i^{eq}} > 2 \cdot \left(\frac{\sum_{i=1}^{n} s_{ie}^{eq}}{\sum_{i=1}^{n} s_i^{eq}}\right)\right] \cdot I[(s_i - s_{ie}) < s_j^*] \cup \left[I(s_i^r = 0) \cdot I\left(s_i^{eq} < P50\left(s_i^{eq}\right)\right)\right]\right\} \quad (2.38)$$

The field *jobs and value added* is used to describe the evolution of energy jobs market as well as the economic performance in the sectors of energy and environmental services by means of value added. In fact, value added is a meaningful indicator for the purpose of evaluating progress in the economic system, being defined as the aggregate value of new goods and services delivered to the society for type of use. In particular, value added is measured in euro and it is calculated as the difference between the value of produced goods and services produced by a certain economic activity and the value of intermediate goods and services consumed by that activity. Selected indicators are then the following ones.

- **Value added in energy & environmental sectors (S/EC-We-J&VA)** $VA_{E\&E}$ **[M€]**

$$VA_{E\&E} = \sum_{i=1}^{n} VA_i \quad (2.39)$$

Value added in energy and environmental sectors $VA_{E\&E}$ is calculated as the sum of value added produced in the ATECO[6] classes D (electricity, gas, steam and air conditioning supply) and E (water supply, sewerage, waste management and remediation activities) [M€].

- **Percentage of occupation in energy&environmental sectors** $VA_{E\&E}$ **[%] (S/EC-We-J&VA)**

$$Empl_{E\&E} = \frac{Empl_D + Empl_E}{\sum_{i=1}^{n} Empl_i} \cdot 100 \quad (2.40)$$

The indicator is calculated as the ratio between the sum of employees in ATECO classes D and E [-] and the total amount of employees [-].

Finally, the field *Investments* is used to investigate trends in the flow of economic resources in the energy and environmental sectors. This is done by means of two indicators:

- **Investments in the energy sector (S/EC-We-Inv) [M€]**

The indicator Inv_{ener} represents the amount of gross fixed capital formation in the economic activities belonging to ATECO class D which entails electric power generation, transmission and distribution, manufacture of gas, distribution of gaseous fuels through mains, steam and

[6] ATECO represents the nomenclature of economic activities used by ISTAT for data dissemination. It is based on NACE classification.

air conditioning supply. Investments are constituted by purchases of fixed capital which consists of material and non-material goods used in productive processes for more than a year.

- **Public expense for environmental protection (S/EC-We-Inv) [M€]**

The indicator $Inv_{pa,env}$ represents the public expenditure for environmental protection. This accounts for all the activities aiming at preventing, reducing, and eliminating pollution and all other form of environmental damage. In detail, the expense takes into account air and climate protection, solid waste and wastewater management, protection of natural resources (soil and water), noise reduction, protection of landscape and biodiversity, research and development for environmental protection, administrative activities, instruction and education regarding the theme of environmental protection.

2.5.7 Socio-economy – Health

"Health" sub-domain is used to analyse possible negative effects on human health due to short/long term exposure to air pollution. Main diseases include stroke, chronic obstructive pulmonary diseases, trachea, bronchus and lung cancers, aggravated asthma and lower respiratory infections. Furthermore, WHO provides evidence of links between exposure to air pollution and type 2 diabetes, obesity, systemic inflammation, Alzheimer's disease and dementia [40]. The impact of atmospheric pollution on human health is further confirmed by EEA estimates: in 2019, approximately 307'000 premature deaths were attributable to $PM_{2.5}$ in the 27 EU Member States.

Given that correlating the number of premature deaths with air pollution exposure is outside the scopes of this work, and no suitable data were found, analysed indicators only focus on the yearly number of deaths due to respiratory (D_r) and cardiovascular (D_c) diseases.

2.6 An aggregate index for municipalities: the Green Transition Index

The process of development of indicators carried out in the previous paragraph generated a total amount of 65 indicators; 4 of these are directly referred to a subdomain whereas each of the other ones is assigned to a specific field. A global view of the indicators is reported in the sunburst plot of *Figure 10*.

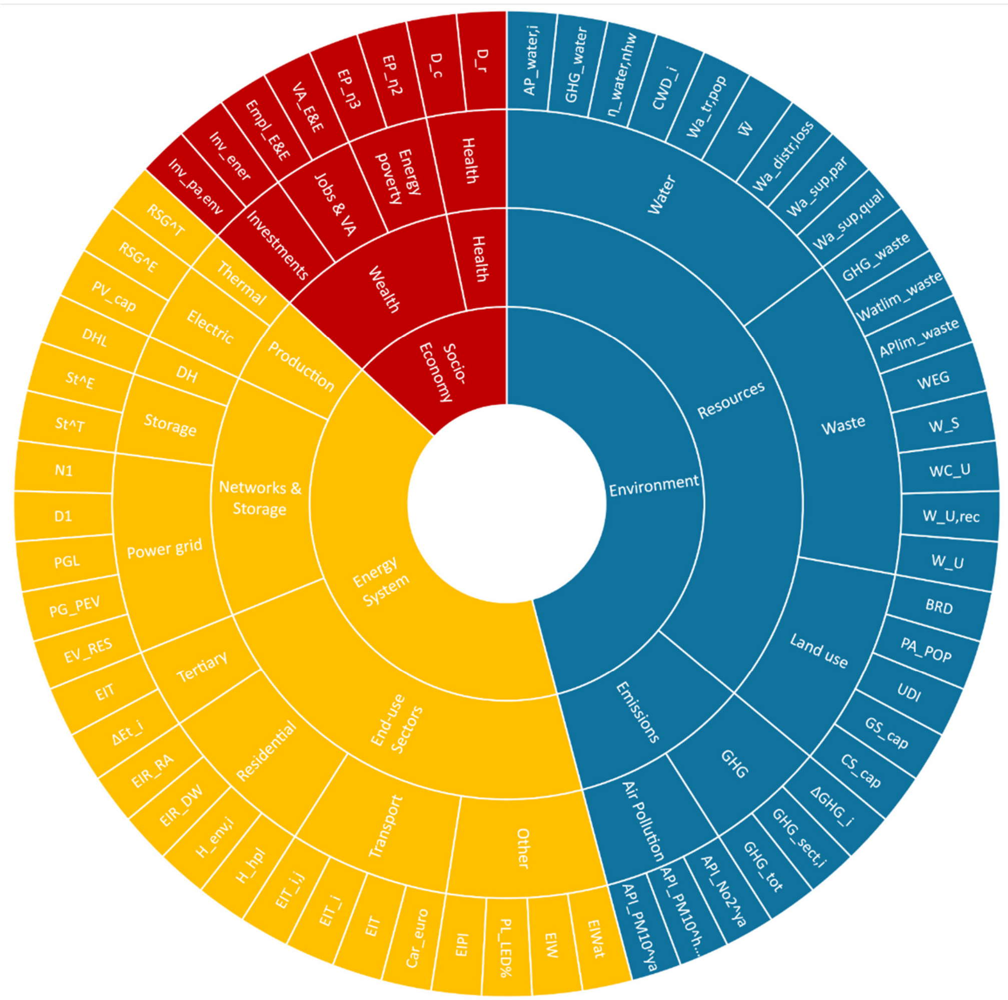

Figure 10. Urban indicators

It can be seen that the most of developed indicators regard the “Environment” domain (28 indicators), followed by the “Energy System” domain (27 indicators, 25 field indicators and 2 sub-domain indicators) and the “Socio-Economy” domain (10 indicators, 8 field indicators and 2 sub-domain indicators); in particular, 6 indicators are cross-field indicators (they can be related to more than one field) and 12 indicators are cross-subdomain indicators (they can be related to more than one subdomain).

2.6.1 Aggregation process

Once the full set of urban indicators has been defined, the next step in the process of building composite indexes is, as stated in paragraph 2.4, to define a subset of *core* indicators which will be normalized and aggregated.

To select core indicators it is necessary, first of all, to define the phenomenon (and/or phenomena) which has to be analysed by means of composite indexes. In this case, starting from the architecture of the database, it has been decided to build aggregate indexes:

- for each domain;
- for all the sub-domains except "Climate" and "Health";
- for all the fields except "Renewable Resources", "Natural gas network", "District Heating network", "Storage Systems", and "Industry".

The reasons for this are mainly data unavailability for the analysed case study (District Heating network, Storage systems, Industry, Health) and the fact that, for the "Climate" subdomain and the field "Renewable Resources", building aggregate indexes is not relevant for policy-making purposes.

The process of aggregation, then, starts from the defined set of core indicators for the selected fields and proceeds until reaching the related domains. Once aggregate indexes have been built for each domain, they can be further aggregated in an unique index, the "Green Transition Index" (GTI), which summarizes information regarding municipal trends in environmental protection and energy system decarbonization, as well as considering the relations of these two domains with the socio-economy sphere (see *Figure 11*).

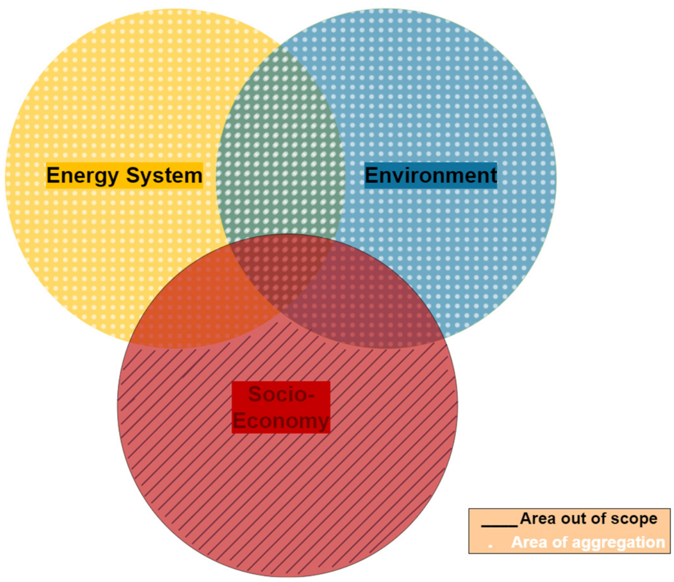

Figure 11. Conceptual scheme of Green Transition Index

The framework for building the Green Transition Index is shown in *Figure 13*. It is characterized by 23 aggregate indexes: 14 aggregate indexes for the fields, 6 for the subdomains, and 3 for the domains. *Table 12* reports the selected core indicators for each field.

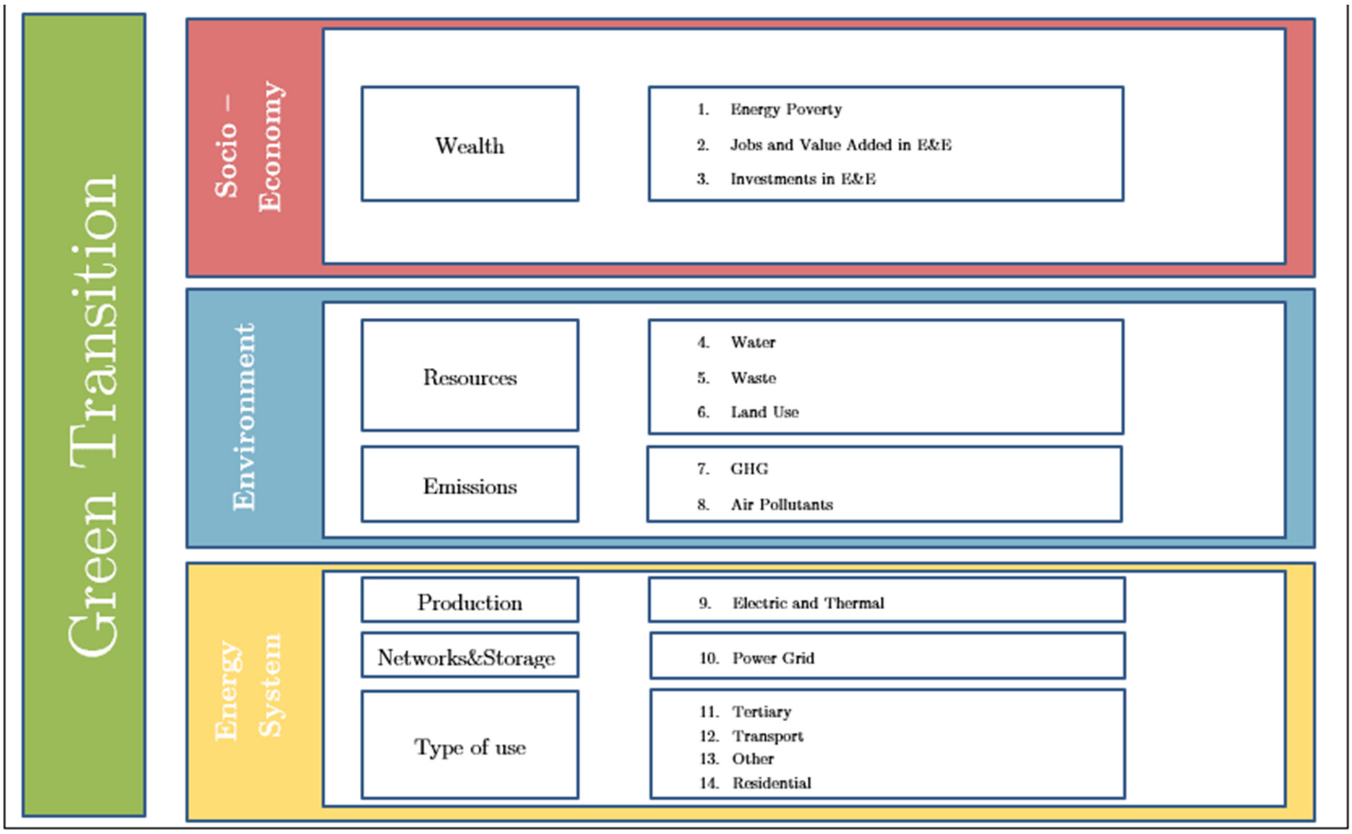

Figure 13. Framework for Green Transition Index (2).

Table 12. Core indicators

FIELD	INDICATOR/INDEX
Energy Poverty	• Energy poverty η_2
Jobs & Value Added in E&E	• Percentage of occupation in energy&environmental sectors
	• Value added energy
Investments in E&E	• Investments in the energy sector
	• Public expense for environmental protection
Water	• Percentage of water distribution losses in aqueduct

	• Average daily consumption of water by inhabitant • Percentage of recycled non-hazardous waste in water integrated service • GHG emissions per equivalent inhabitant in water integrated service • Atmospheric pollutants per equivalent inhabitant in water integrated service
Waste	• Urban waste generation per capita • Recycling rate of solid waste • Expenditure on urban waste management per capita • Gross energy generation per quantity of treated waste • Special waste generation per capita • Number of exceedances of limits for atmospheric pollution in waste disposal process
Land Use	• Green surface per capita • Consumed soil per capita • Urban dispersion index • Cycle-pedestrian areas
GHG	• GHG Emissions
Air Pollution	• NO_2 yearly average concentration • PM_{10}
Electrical and Thermal	• Total energy generation from renewable energy sources
Power Grid	• Grid quality • Power grid losses
Tertiary	• Energy intensity in tertiary sector
Transport	• Energy intensity in transport sector

Other	• Energy consumption per number of public spot lighting • Energy Intensity in solid waste management • Energy Intensity in wastewater management
Residential	• Climate-corrected energy intensity in residential sector by floor area

It can be seen that, of the initial set of 65 indicators, only 35 indicators have been selected; some of them are first aggregated between each other to build simple indexes which are then used in the process of aggregation at the field level. For example, the PM_{10} index is obtained as the result of aggregation of the indicators API_{PM10}^{ya} and API_{PM10}^{hae}, whereas the index Power Grid is obtained as aggregation of indicators D5 and N1. The complete list of core indicators, basic, and aggregate indexes and the related equations used for the Green Transition Index can be found in the formalization tables reported in the Appendix.

After core indicators have been defined, to calculate basic and aggregate indexes, the selected indicators must be normalized. The process of normalization consists in the adjustments of indicators onto a common scale, and it is necessary to compare and aggregate indicators having different units of measurement and different ranges of variation.

In literature, many normalisation methods exist [21],[41]. They include, for example, standardization (or z-score method), re-scaling (or min-max method), and other methods based on ordinal scale. Standardization method converts the indicators to a common scale of mean zero and standard deviation of one [21]; however, normalized indicators obtained through this method have different range of variations, depending on input data. On the other hand, the min-max method allows to rescale indicators, such that normalized indicators will range in a predefined interval (e.g. 0-1, 0-100). However, this comes at the cost of losing information about the variance of the original set of indicators. Finally, ordinal scales methods classify indicators into ordered categorical classes. For this work, it has been decided to adopt the min-max normalization method as both standardization method and ordinal scales methods are not considered to be effective for the goal of this work. In fact, an essential requirement for the developed framework is that normalized indicators must have the same range of variation to be aggregated, and this does not occur in case of choosing standardization method. Furthermore, since the aggregation process is based on arithmetic operations and, in ordinal scale methods, normalized indicators are based on categorical classes, the aggregation process cannot be performed as well by choosing this kind of normalization procedure.

In the min-max method, each indicator is normalized by means of:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - \min_{t}(x_{qc})}{\max_{t}(x_{qc}) - \min_{t}(x_{qc})} \qquad (2.41)$$

where I_{qc}^{t} is the normalized indicator, x_{qc}^{t} represents the indicator for a generic city c and time t, and $\min_{t}(x_{qc})$ and $\max_{t}(x_{qc})$ are the minimum and maximum value of x_{qc}^{t} across all time units t. In theory, another meaningful normalization could be:

$$I_{qc}^{t} = \frac{x_{qc}^{t} - \min_{c}(x_{q}^{t})}{\max_{c}(x_{q}^{t}) - \min_{c}(x_{q}^{t})} \qquad (2.42)$$

In this case, normalization is carried out by considering the minimum and maximum value of the indicator across all cities c for each time unit t. This kind of normalization allows to consider different performances across cities and encourages for comparisons among urban policymakers. However, given that extending data collection to different municipalities is outside the scope of this thesis, it has been decided to collect data for a unique municipality, benchmarking the value of a certain indicator with the relative minimum/maximum values across years.

When normalizing with the purpose of creating aggregate indexes, it is also needed to take into account the sign of the indicators, i.e. the positive or negative orientation towards the index. If, for example, a higher value of a certain indicator symbolizes a lower performance of the related aggregate index, this should be taken into consideration by substituting (2.40) with the following:

$$I_{qc}^{t} = \frac{\max_{t}(x_{qc}) - x_{qc}^{t}}{\max_{t}(x_{qc}) - \min_{t}(x_{qc})} \qquad (2.43)$$

Once all indicators have been normalized, i.e. for each indicator it has been calculated the related basic index, the last steps in defining aggregate indexes are to choose a *weighting scheme* and to define the *aggregation method*.

The weighting scheme is a collection of sets of weights assigned to indexes, used to build aggregate indexes at different level (field, subdomain, domain levels and GTI). In particular, a weight has to be assigned to each simple/aggregate index.

The choice of weighting scheme is a delicate task given that weight have a strong impact on the final aggregate indicator score and, also, different stakeholders could have different opinions on choosing weighting scheme. For this work, it has been decided to stick to the most used and straightforward to communicate scheme, the equal weights scheme, avoiding conferring more importance to some indicators than others. As a result, each index will have the same weight of all the other indexes used for calculating a given aggregate index.

Concerning the choice of aggregation method, instead, the two main methods are arithmetic and geometric mean (the mathematical formulation is reported in *Table* 13).

Table 13. Arithmetic and geometric mean

Arithmetic mean μ_a	Geometric mean μ_g
$\mu_a = \sum_{i=1}^{n} \frac{x_i}{n}$	$\mu_g = \sqrt[n]{\prod_{i=1}^{n} x_i}$
where x_i is the i-th of the n measures	

Using arithmetic mean, underperformance in one component can be perfectly compensated by equivalent overperformance in another (perfect substitutability), whereas geometric mean is used to avoid compensation of low performances of some indicators by high performance on others, which occurs only partially. For example, if a hypothetical composite index I were formed by 5 indicators (normalized in scale 1-10) with values 4, 4, 4, 4, 4 for a city A and 8, 8, 1, 2, 1 for a city B, the value of the composite index would be equal (I_a=I_b=4) for both cities if evaluated through arithmetic mean aggregation, but quite different (I_a=4, I_b=2.64) if evaluated by means of geometric mean aggregation, penalising the city having unbalanced performances in underlying indicators (i.e. low scores in some indicators). Still, an increase of one unit in the score of one of the low-values indicators for city B (e.g. indicator score changes from 1 to 2) is much more beneficial than the same increase for an indicator of city A (e.g. indicator score changes from 4 to 5), as the composite index would increase its score by 14.8% in the first case (from I_b=2.64 to I_b'=3.03) against 4.6% in the second case (from I_a=4 to I_a'=4.2%), showing that cities with lower scores in individual indicators would have greater incentive to improve its performances in the dimensions of low-values indicators.

In this work, arithmetic mean, which is the most used in the international scene when computing indices [42], has been chosen as aggregation method; the reason for this stands in the fact that, at the present moment, the metric framework is applied to a unique city and there is no particular advantage in using geometrical mean.

2.6.2 Statistical and conceptual coherence

In this paragraph, an analysis of the statistical and conceptual coherence of the developed aggregate indexes is presented.

When building aggregate indexes, the most important drawback is the presence of a certain degree of trade-off among the underlying components. For example, if an aggregate index is built as the result of arithmetic mean of two simple indexes having opposite trends in the analysed time span (one increases, the other one decreases), the aggregate index will not be representative neither of the first nor of the second indicator but, instead, would show a "halfway" behaviour. In theory, this phenomenon should be avoided as much as possible, for example by modifying the framework and/or changing the indicators used in the aggregation process. However, in this case, given that the target of the analysis is a multi-dimensional phenomenon which involves many different aspects, a certain degree of trade-off in building aggregate indexes is accepted.

To properly account for the relationship between an index and its underlying components, correlation can be used. Correlation is a measure of statistical dependence between one variable and another; in particular, in statistics, correlation is usually evaluated by looking at linear relations between the analysed variables. This can be measured by means of Pearson correlation coefficient $r_{x,y}$ which is defined as:

$$r_{x,y} = \frac{cov(x,y)}{\sigma_x \cdot \sigma_y} \qquad (2.44)$$

where cov is the covariance, σ_x is the standard deviation of x and σ_y is the standard deviation of y. As it can be seen from (2.44), Pearson correlation coefficient is a normalized measurement of the covariance, such that the result always has a value between -1 (perfect inverse correlation) and 1 (perfect correlation). *Figure 14* shows some examples [43] of scatter diagrams with different value of Pearson correlation coefficient.

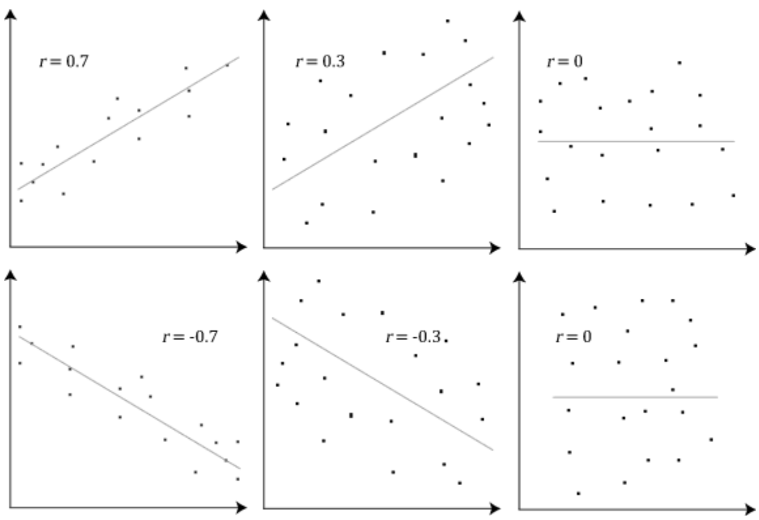

Figure 14. Scatter diagrams and Pearson Correlation Coefficient

The correlation analysis for the adopted framework involves the evaluation of the Pearson correlation coefficient between the following pair of variables:

- indicators and aggregate indexes at field level
- aggregate indexes at field level and subdomain level
- aggregate indexes at subdomain level and domain level
- aggregate indexes at domain level and GTI.

In general, it is considered to have good levels of correlation between variables if the Pearson correlation coefficient assumes values between 0.4 and 0.8 [41]; the analysis for the selected case study, which shows good results for most of the indicators and related indexes, is reported in chapter 3.

3 A case study: the city of Turin

In the present chapter, the methodology described above is applied to the case study of Turin city. Turin is an Italian municipality with 842,754 inhabitants, localized in Piemonte region and administrative center of the Turin Metropolitan Area. For the present analysis, it has been considered the functional urban area (FUA) composed by the area englobed in municipal administrative boundaries, together with facilities serving the city for energy generation, waste, and wastewater treatment (see *Figure 15*).

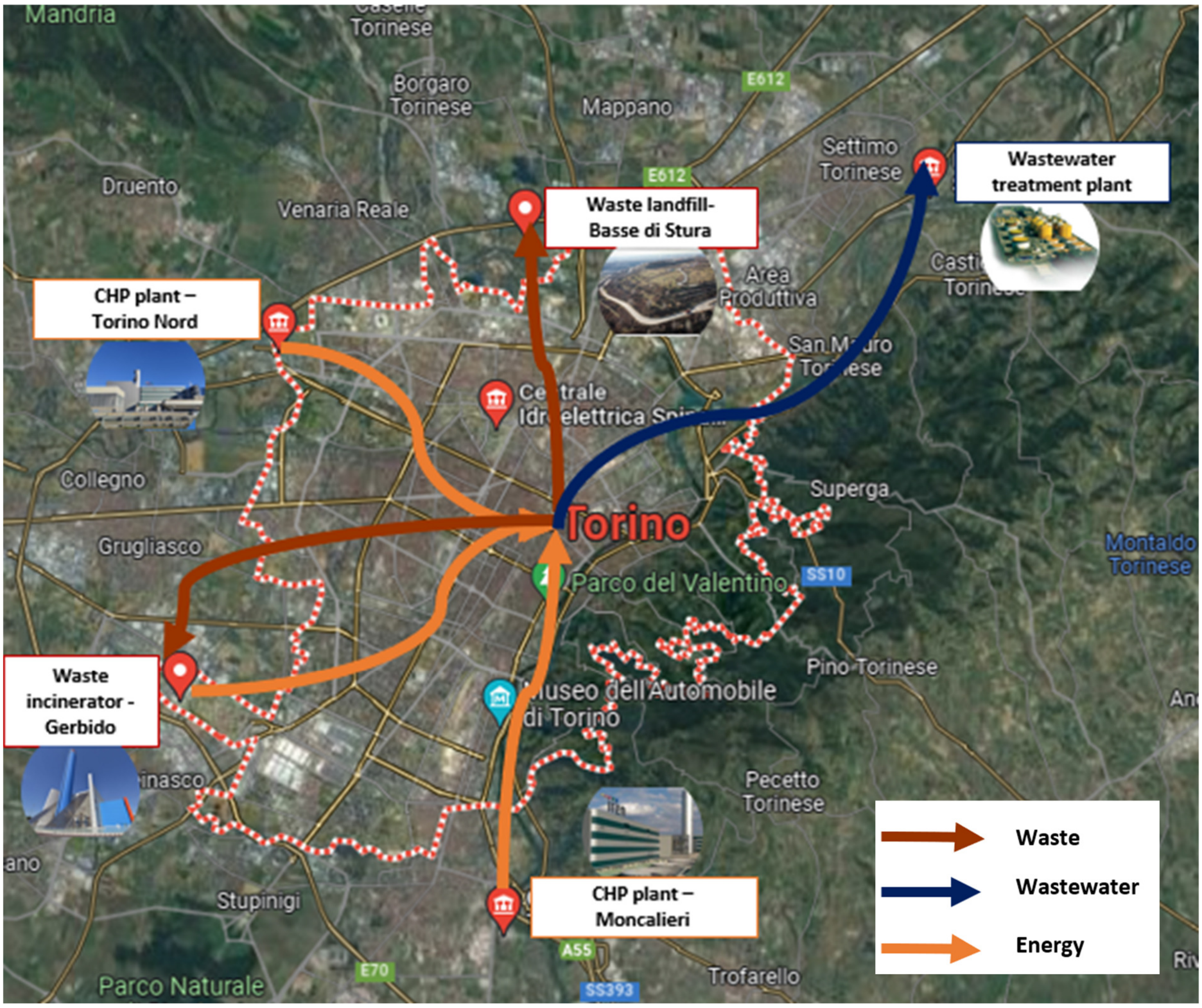

Figure 15. Area of analysis

After a short description of the available datasets, indicators and indexes are built and analyzed. The collection of data is conducted by following the hierarchical structure described in the previous section and has the aims of providing a global view of the available data for the selected case study, as well as to highlight what data need to be added to build a more complete database, which would enable for a better eco-energetic planning. Analyses are carried out for the time span 2014-2019, according to data availability. The next paragraphs show a general view of the collected datasets, categorized by subdomain, and a short description of the main ones, whereas the complete mapping of both datasets and downloaded data, structured following the formalization procedure, can be found in Appendix. It has to be noted that, even if some datasets belong to more than one domain, in the following chapters they are reported only once to avoid redundancy.

3.1 Datasets - Energy System

The energy system domain, containing 29 datasets, represents the largest one. *Table* 14 reports all the datasets and the related sub-domains.

Table 14. Datasets in the energy system domain

Dataset name	Sub-domain
Impianti produzione energia elettrica	Production
Impianti di produzione di calore	Production
Catasto Impianti Termici	End-use sectors
TERNA - Statistiche regionali	Production, end-use sectors
Iren - Bilancio di sostenibilità 2021	Networks&Storage
Ambiente urbano - Energia 2020	Networks&Storage
Mobilità - stazioni ricarica veicoli elettrici	Networks&Storage
GTT - Dichiarazione non finanziaria 2020	End-use sectors
Open Parco Veicoli	End-use sectors
5° RAPPORTO NAZIONALE SULLA SHARING MOBILITY – 2021	End-use sectors
Gas Distribuito Province	End-use sectors
Consumi di gas naturale per comune	End-use sectors
Autoritratto 2021 – Circolante	End-use sectors
Vendite (consumi) provinciali di benzina, gasolio e olio combustibile	End-use sectors
Vendite provinciali di GPL e lubrificanti	End-use sectors
Ambiente urbano - Eco management	End-use sectors
Dettaglio attestato di prestazione energetica (APE) - sezione dati energetici	End-use sectors
Dettaglio attestato di prestazione energetica (APE) - sezione impianti	End-use sectors
Consumi energetici, Impianti e Attestazione di Prestazione Energetica - APE	End-use sectors
TAPE	End-use sectors
Piano di sviluppo IRETI	Networks&Storage
Ambiente urbano - Mobilità	End-use sectors
Torino - Informacasa	End-use sectors
Analisi del potenziale solare per i comuni dell'area metropolitana torinese	Production
Dichiarazione ambientale - Termovalorizzatore Gerbido	Production
STATO D'AVANZAMENTO ATTIVITA' DISCARICA E ATTIVITÀ DI GESTIONE DEL BIOGAS	Production
Dichiarazione ambientale - Centrale di cogenerazione Torino Nord	Production
Annuario statistico – Settore Toponomastica ed Edilizia	End-use sectors
Dichiarazione ambientale - Centrale di cogenerazione Moncalieri	Production

The production sub-domain contains data regarding the installed capacity of both electricity and thermal energy production units, like solar PV systems, biogas-based turbines, hydroelectric power plants, CHP units as well as condensing boilers, heat pumps, biomass burners and solar thermal heaters. These data are obtained by GSE, ISTAT (concerning yearly PV production) and reports by the managing institution of the main plants at municipal level (IREN), which also provide data about total energy production and plant efficiencies. Unfortunately, no further data about yearly gross electricity production by energy source is available at municipal level, and, consequently, provincial values (provided by TSO) have been included in the database. Concerning the Network&Storage sub-domain, some data for district heating network are retrieved from the sustainability balance of the network administrator, but many other data regarding thermal energy consumption of final users and network operation (like temperature and pressure values) are not available. This is also true for power grid, while a full dataset containing information about EV charging systems is provided by the municipality.

Datasets belonging to the subdomain of end-use sectors constitutes the largest fraction of the available ones. The collected datasets provide different values about the final energy consumption by sector and/or by carrier. In this context, a very useful dataset is the one provided in TAPE (Turin Action Plan for Energy) [44]. The report is part of a larger initiative, known as Covenant of Mayors, which gathers local governments committed to achieving the EU climate and energy targets. Even if all the data contained in TAPE are obtained as an elaboration of simpler raw data, as many of the datasets used as source for analyses in TAPE are not public available, it has been decided, for the present moment, to include it in the database. In particular, the emission inventory for each end-use sector is reported, after the evaluation of final energy consumption by carrier. However, among GHG emissions, only CO_2 amount is evaluated, by applying different emission factors for each energy carrier.

Concerning other datasets, a valuable source to evaluate the technologies used for heating purposes in different sectors, could be “Catasto Impianti Termici” but it is not available for public consultation. However this information is available, even if partially, in the datasets “Dettaglio attestato di prestazione energetica (APE)”, retrieved by Regione Piemonte, which also provide data about buildings’ energy performance in residential and non-residential buildings. Neverthless, given that out of 502,767 residences only 142,705 records about both residences and buildings are known, these data are not sufficient to evaluate the current energy performances of the household and buildings sectors.

The transport sector is detailed by means of datasets provided by multiple data sources like ACI, GTT and ISTAT. The collected data regard, for example, the number of vehicles by category, fuel and emitting class, as well as energy consumption and total emissions in the public transport sector. Information regarding traffic fluxes is collected by the society 5T and is not public available. Finally, the remaining datasets contains data of fossil fuel trades at provincial level.

3.2 Datasets - Environment

The environment domain is built by considering mainly data from the regional agency for environmental protection (ARPA PIEMONTE), the national institute ISPRA ("Istituto Superiore per la Protezione e la Ricerca Ambientale") and the World Bank Group. *Table* 15 reports all the datasets in the environment domains and the related sub-domains.

Table 15. Datasets in the environment domain

Dataset name	Sub-domain
Ambiente urbano - Verde Urbano	Resources
Aria - la qualità dell'aria in Piemonte (Misure)	Emissions
Bilancio di Sostenibilità - SMAT	Resources
Consumo del suolo	Resources
Dati di gestione dei rifiuti urbani	Resources
Dati di produzione e raccolta differenziata	Resources
Dati sui costi di gestione dei rifiuti urbani (pro capite o per chilogrammo di rifiuto)	Resources
Escursione termica diurna	Climate
GHSL – Global Human Settlement Layer	Resources
Giorni consecutivi senza pioggia (CCD)	Climate
Giorni di vento	Climate
Global solar atlas	Resources
Global wind atlas	Resources
Gradi giorno di riscaldamento	Climate
Inventario Nazionale delle Emissioni in Atmosfera su base provinciale	Emissions
Inventario Regionale delle Emissioni in Atmosfera (IREA)	Emissions
Istat Tavole Censimento acque per uso civile	Resources
Precipitazioni e anomalie	Climate
Rapporto sul consumo di suolo 2021	Resources
Rifiuti - Produzione rifiuti speciali	Resources
TAPE	Emissions
Temperature	Climate

Climate data regard minimum and maximum yearly temperatures and thermal excursion, heating degree days, yearly mean wind velocity and rainfall values. Concerning the emission sub-domain, many values with different temporal and spatial granularity have been found. First of all, ISPRA provides the national emission inventory on provincial scale for both GHG emissions and atmospheric pollutants. These data are obtained as the result of a top-down process which disaggregates the national emissions on provincial level. The inventory is based on EMEP-CORINAIR nomenclature which classifies emitting activities by SNAP97 (Selected Nomenclature for Air Pollution) [45]. This classification has a hierarchical structure characterized by 11 macro-sectors, 56 sectors and 360 categories. In particular, the following macro-sectors are identified:

- 01: Combustion - Energy and processing industry
- 02: Combustion - Non industrial plants
- 03: Combustion - Manufacturing industry
- 04: Production processes
- 05: Extraction and distribution of fossil fuels and geothermal energy
- 06: Solvent use
- 07: Road Transport
- 08: Other mobile sources and machinery
- 09: Waste collection, treatment and disposal activities
- 10: Agriculture
- 11: Other sources and sinks

The inventory provided by ISPRA referred to 2019 is the most recent one; however, its main drawbacks are related to the geographical scale, which is not municipal, as well as the fact that the top-down methodology proposed is not very precise. Instead, data contained in the inventory provided by Regione Piemonte (IREA) have a municipal scale, and they are obtained by means of the software INEMAR which is based on a bottom-up approach [46]. At the present moment, data are only available for 2015 and, in the view of creating a database which can allow one to track data with continuity, it should be evaluated if this dataset will be updated in the next years.

Another valuable dataset regarding the "emission" sub-domain is "Aria - la qualità dell'aria in Piemonte" which provides direct measurement of main atmospheric pollutants (NO_X, CO, PM_{10}, $PM_{2.5}$, SO_2, Arsenic, Benzopyrene, Cadmium, Nichel, Lead and other aromatic hydrocarbons) at the level of measurement stations.

In the "resources" sub-domain, four datasets provide information regarding the field of soil use. Raw data refer to the extension of green areas and consumed soil, whereas basic figures relate to local temperature variations and ecosystem services loss due to soil consumption ("Rapporto sul consumo di suolo 2021").

Concerning the waste field, datasets have been gathered with the purpose of recreating the waste management process, from the reception to the final disposal. In this context, ISPRA datasets provide information regarding the total amount of municipal wastes by category, as well as the typology of plants used to treat waste and the related costs; ARPA, instead, further supplies data regarding special wastes (industrial/non-industrial).

The water field is mainly detailed by means of the annual report provided by SMAT (Società Metropolitana Acque Torino), which provides a lot of basic figures regarding the entire process of water integrated service, from supply to wastewater treatment. The only drawback of this dataset is the spatial granularity which is not municipal but covers all the municipalities served by the society.

Finally, the remaining datasets in the "resources" subdomain are used to gather data about solar and wind availability.

3.3 Datasets - Socio/Economy

Concerning the socio/economy domain, data are mainly collected from national entities, like ISTAT, Ministero dell'Economia e Finanze (MEF), Ministero dello sviluppo economico (MISE), and ARERA, but also from local entities like Regione Piemonte and Camera di Commercio, Industria, Artigianato e Agricoltura di Torino.
In the perspective of developing the eco-energetic planning of the city, the data searching mainly focuses on the domains which can be related to the ones of energy system and environment. *Table* 16 reports the found datasets and the related sub-domain:

Table 16. Datasets in the socio/economy domain

Dataset name	Sub-domain
Numero aziende per comune e classificazione Ateco 2007 - sede legale in Piemonte	Wealth
Prezzi medi nazionali dei carburanti e combustibili	Wealth
Prezzi dell'energia elettrica per i consumatori domestici per classe di consumo - UE e area Euro	Wealth
Prezzi dell'energia elettrica per usi industriali per classe di consumo - UE e area Euro	Wealth
Prezzi finali del gas naturale per i consumatori domestici per classe di consumo - UE e area Euro	Wealth
Prezzi del gas naturale per usi industriali per classe di consumo- UE e area Euro	Wealth
Listino quindicinale prezzi	Wealth
AAEP - Anagrafe delle Attività Economiche Produttive - Consultazione	Wealth
Popolazione residente ricostruita	Wealth
Reddito e principali variabili IRPEF su base sub-comunale/comunale	Wealth
Principali aggregati territoriali di Contabilità Nazionale - Valore aggiunto per branca di attività	Wealth
Imprese e addetti	Wealth
Principali aggregati territoriali di Contabilità Nazionale - Investimenti fissi,lordi,interni	Wealth
Spesa per consumi finali delle amministrazioni pubbliche	Wealth
Indagine sulle spese delle famiglie: microdati ad uso pubblico	Wealth
Mortalità per cause	Health

It can be seen that most of the datasets found for the case study are referred to the wealth subdomain. In particular, data regarding family expense, used to build energy poverty indicators, are provided by ISTAT, even if they are not referred to the municipality but to the regional level. Concerning the Jobs & Value Added field, both "Imprese e Addetti" dataset, which tracks trends in occupation by distinguishing among the various NACE categories, and "Valore aggiunto per branca di attività" dataset, which provides information regarding value added by NACE category, are referred to municipal level. In the Investment field, the dataset "Investimenti fissi, lordi, interni" contains data of investments by NACE activity and "Spesa per consumi finali delle amministrazioni pubbliche" shows expenses of the public administration distinguishing among expense categories. Again, these two datasets, are referred to regional level.

The wealth subdomain is also populated with data regarding population, income, and energy commodity prices.

On the other hand, the health sub-domain includes data regarding number of deaths whose cause are diseases linked to environmental pollution.

3.4 Elaborated data: indicators

The data collection carried out for the analysed case study involved a total amount of 67 datasets and 174 downloaded data, whose formalization attributes can be found in Appendix. Of these, only a fraction (35 datasets, 90 downloaded data) has effectively been used for building indicators; the formalization tables have then been restricted and reported in Appendix.

Concerning elaborated data, an analysis of all the indicators shown in paragraph 2.4 is presented, highlighting eventual missing data and/or approximations done to build indicators and indexes for the case study; for all the developed indicators, the timespan of analysis is from 2014 to 2019. Appendix also reports the formalization table for elaborated data used for indexes aggregation purposes.

3.4.1 Energy System - Production

The energy production system of Turin city is characterised by two CHP plants, two thermal integration plants for district heating, two small hydroelectric plants, a waste incinerator, a waste landfill producing biogas, and distributed energy production plants like photovoltaic systems, solar heaters, solid biomass burners and heat pumps.

The two CHP plants, which are the Moncalieri thermoelectric plant, localised in the south-east area of the city, and the Torino Nord thermoelectric plant, localised in the north-east area, are both managed by IREN and produce electricity and heat, also serving the municipal district heating network. The plants are characterised by high efficiencies in cogeneration mode (85-90%) and have an electrical capacity of 785 MW and 390 MW respectively (only-electricity generation mode) [47] [48].

Two additional thermal integration plants for district heating are also present in the municipality; these are the “Politecnico” plant and BIT plant characterized respectively by a thermal capacity of 255 MWt and 85 MWt.
Concerning the hydroelectric plants, they are both mini hydro plants taking advantage of small waterfall. One turbine (2 MW) is installed near Moncalieri thermoelectric plant, whereas the other one (0.434 MW) fulfils part of the energy demand of the technologic centre EnviPark.
Waste-to-energy plants are a waste incinerator and a waste landfill (Discarica Basse di Stura) which, even if not used anymore for waste disposal from 2009, still produces biogas due to old disposed garbage. In particular, biogas is extracted and used for electricity production through internal combustion engines. The waste incinerator (Gerbido), instead, is characterised by an electrical capacity of 65.5 MW and, from 2020, works in cogeneration mode, producing heat for serving district heating network. However, not the entire energy generation from waste incinerator is accounted as renewable energy, given that, as stated in paragraph 2.5.1, only the amount of energy produced from biodegradable fraction of waste can be considered renewable. In particular, the amount of biodegradable fraction of waste, calculated as the sum of biodegradable waste produced in canteens, gardens, parks, open-air markets and from domestic composting, accounts for about 1% of the total treated waste in the incinerator.
Concerning solar energy plants, total installed capacity of PV systems in the municipality has been increasing in the recent years, reaching almost 23.65 MW [49] in 2019 whereas data regarding total solar collector surface are not public available. This also holds true for solid biomass burners and heat pumps, for which data regarding total installed capacity are not available as well. In fact, even if GSE provides these kinds of data through the dataset “Atlaimpianti”, they are only partial and not representative. *Table* 17 reports the trends of all the indicators of the production field.

Table 17. Indicators of the production field

Indicator	2014	2015	2016	2017	2018	2019
RSG^E[GWh/y]	82.5	74.2	65.8	61.0	58.2	55.3
RSG^T[GWh/y]	35.3	35.3	35.3	35.8	35.8	26.6
RSG [GWh/y]	117.9	109.5	101.1	96.8	94.0	81.9
RSP [%]	0.847	0.939	0.872	0.846	0.835	0.777
PV_{cap}[%]	-	-	8.6	9.4	9.8	10.3

It can be seen that both the electrical and thermal energy produced from renewable energy sources decreased in the considered years.
Concerning electrical energy, the decrease in production is due to the closing of waste landfill, which gradually reduced the amount of biogas generation in the years, and the reduction in hydroelectric energy production (see *Figure 16*). On the other hand, PV production increased

from 18 to 22 GWh/y, as also shown by the indicator PV_{cap}; however, still a small fraction of the installable capacity has been installed in the municipality (10.3%).

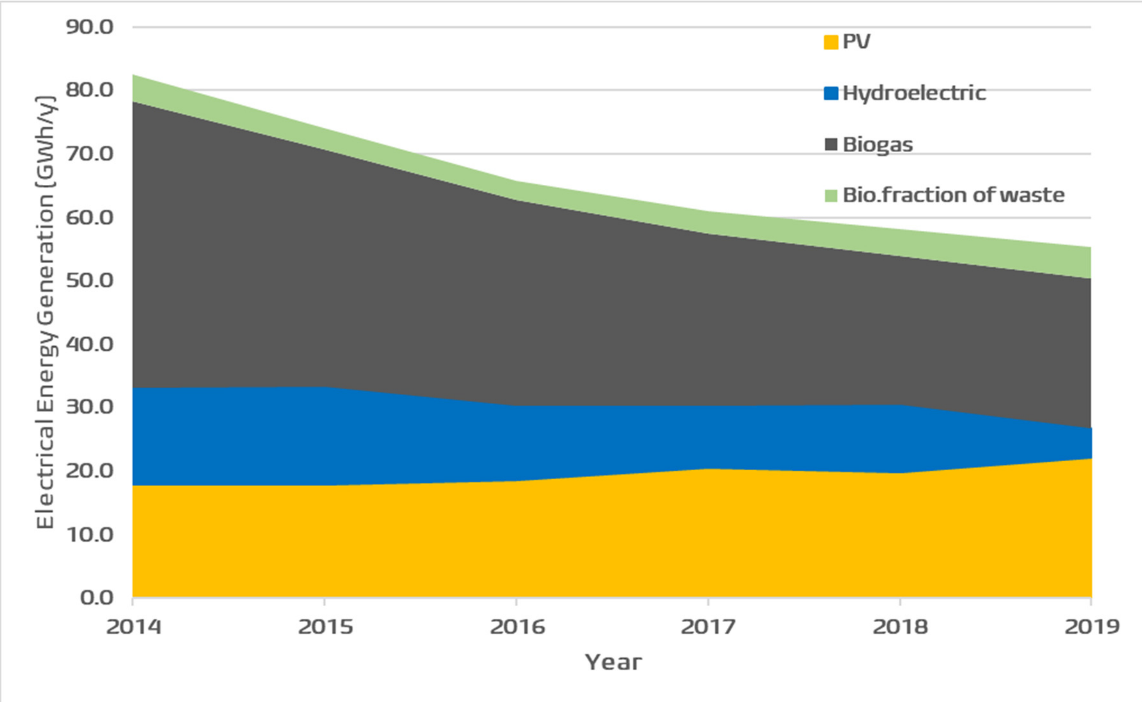

Figure 16. Electrical energy generation from renewable energy sources (Data from [47]–[51]*).*

In relation to thermal energy production, instead, it has to be highlighted that data from 2014 to 2017 regarding generation from solid biomass are not available, and they are inferred; in particular, for these years, it has been assumed the same thermal energy generation of 2018.
The decrease in gross thermal energy generation from 35.3 GWh/y (2014) to 26.6 GWh/y (2019) is due to the reduction in energy production from solid biomass whereas the amount of energy produced from solar heaters has been slightly increasing from 2.7 GWh/y in 2016 to 3.1 GWh/y in 2019. It has to be noted that reduction in renewable thermal energy generation from solid biomass could be related to higher average winter temperatures and/or switching in domestic heating technology (e.g. to district heating).
As a result, the indicator of aggregate energy generation from renewable energy sources (RSG) shows a negative trend in the timespan of analysis, as well as for the percentage of renewable energy production on final energy consumption (RSP), which is less than 0.8% in 2019.
It has to be noted, however, that the contribution of thermal energy generation from heat pumps, which could be important at the municipal level, was not included due to lack of data. Moreover, given that data are partially available for 2022 year, the thermal energy generated from heat pumps in that year has been evaluated by adopting methodology proposed in Directive 2009/28/CE and Decision 2013/114/UE which considers as renewable thermal energy the quantity of heat E_{RES} withdrawn from external ambient air, water or subsoil, and calculated as:

$$E_{RES} = Q_{usable} \cdot \left(1 - \frac{1}{SPF}\right) \quad (3.1)$$

where

$$Q_{usable} = H_{HP} \cdot P_{rated} \quad (3.2)$$

is the total usable heat delivered by heat pumps [GWh], H_{HP} is the equivalent full load hours of operation in a year [h], P_{rated} is the total capacity of heat pumps installed, and SPF is the estimated average seasonal performance factor. Parameters H_{HP}, SPF are standardized by tables provided by the directive and depend on climate conditions of the analysed area as well as the typology of heat pump (see *Table 18*).

Table 18. Default values for H_{HP} and SPF for electrically driven heat pumps [52]

Heat Pump Energy source	Energy source and distribution medium	Climate conditions					
		Warmer climate		Average climate		Colder climate	
		H_{HP}	SPF (SCOP$_{net}$)	H_{HP}	SPF (SCOP$_{net}$)	H_{HP}	SPF (SCOP$_{net}$)
Aerothermal energy	Air-air	1,200	2.7	1,770	2.6	1,970	2.5
	Air-water	1,170	2.7	1,640	2.6	1,710	2.5
	Air-air (revers.)	480	2.7	710	2.6	1,970	2.5
	Air-water (reversible)	470	2.7	660	2.6	1,710	2.5
	Exhaust air-air	760	2.7	660	2.6	600	2.6
	Exhaust air-water	760	2.7	660	2.6	600	2.6
Geothermal energy	Ground-air	1,340	3.2	2,070	3.2	2,470	3.2
	Ground-water	1,340	3.5	2,070	3.5	2,470	3.5
Hydrothermal heat	Water-air	1,340	3.2	2,070	3.2	2,470	3.2
	Water-water	1,340	3.5	2,070	3.5	2,470	3.5

For the present analysis, since data regarding the typology and efficiencies of heat pumps are missing, it has been assumed to consider a "standard" heat pump of the typology air-water, electric, which is, probably, the most diffused type and allows for a conservative estimation of H_{HP}. Being Turin part of the "colder climate" area, the selected standard values are then $H_{HP} = 1{,}710$ and $SPF = 2.5$.
To estimate the remaining input parameter P_{rated}, data from the dataset "Dettaglio attestato di prestazione energetica (APE) - sezione impianti" have been used. The dataset comprises various data regarding energy labels of buildings in Piemonte region and, in particular, the category of energy service (heating only, cooling only, domestic hot water only, combined plants), the name of the appliance and the related capacity [kW].
Given the large dimensions of the dataset (a CSV file of 1,402,473 rows and 55 columns), the data processing has been carried out with a Python script, which is reported in Appendix. In particular, the script:

1. filters Turin buildings' data from the data of Piemonte region;
2. filters non-residential buildings and residential buildings which are permanently inhabited;
3. filters by appliances used for heating purposes;
4. filters by appliances supplied with electricity;
5. filter appliances by means of a dictionary containing the names of the main producers of heat pumps, avoiding possible outliers;
6. extract the values of installed capacity for each heat pump.

As a result, the total installed capacity amounts to 195.31 MW, with a yearly production of renewable thermal energy of 200.4 GWh/y which accounts for 10.5% of the estimated production in Piemonte region, basing on values reported in [24]. However, it has to be pointed out that the analysed dataset contained many outliers and unprecise values which could lead to distorted results, and that only about 30% of the residences in the city were covered by the dataset.

3.4.2 Energy System – Networks & Storage

The characterization of the "Networks & Storage" subdomain for Turin city involves the analysis of the district heating network, which is the largest in Italy covering 73.2 Mm^3 in the whole metropolitan area, of the power distribution grid, and of distributed storage systems.
In the view of defining the set of indicators presented in 2.5.2, however, only a fraction of data seems to be public available. In particular, data needed for building the indicators DHL and St^E are totally missing. *Table* 19 reports the calculated indicators.

Table 19. Indicators in the Networks & Storage subdomain

Indicator	2014	2015	2016	2017	2018	2019
$N1$ [-]	1.17	1.36	1.3	1.69	1.37	1.43
$D1$ [-]	21.5	19.81	31	25.39	28.7	25.7
PGL [%]	6.08	5.87	4.65	3.91	4.17	4.23
PGQ [-]	0.92	0.82	0.38	0.25	0.41	0.49
PG_{PEV} [-]	-	0.114	0.111	0.325	0.722	0.670
EV_{RES} [%]	-	-	20.00	3.13	0.72	2.27

It can be seen that all the indicator refers to the power grid. Concerning the index "Power Grid Quality" PGQ, which is calculated as the average of normalized N1 and D1 indicators, it can be observed a worsening trend until 2017 which is reverted in 2018 and 2019. However, both indicators N1 and D1 are pretty stable in the timespan of analysis. Power grid losses, instead, tend to decrease in the years from 6.08% in 2014 to 4.23% in 2019, with a minimum of 3.91% in 2017, testifying the investments of the local distribution system operator. *Figure*

17 shows the trends of normalized power grid quality and power grid losses; a higher value of the normalized indicator is associated to an improvement in performances.

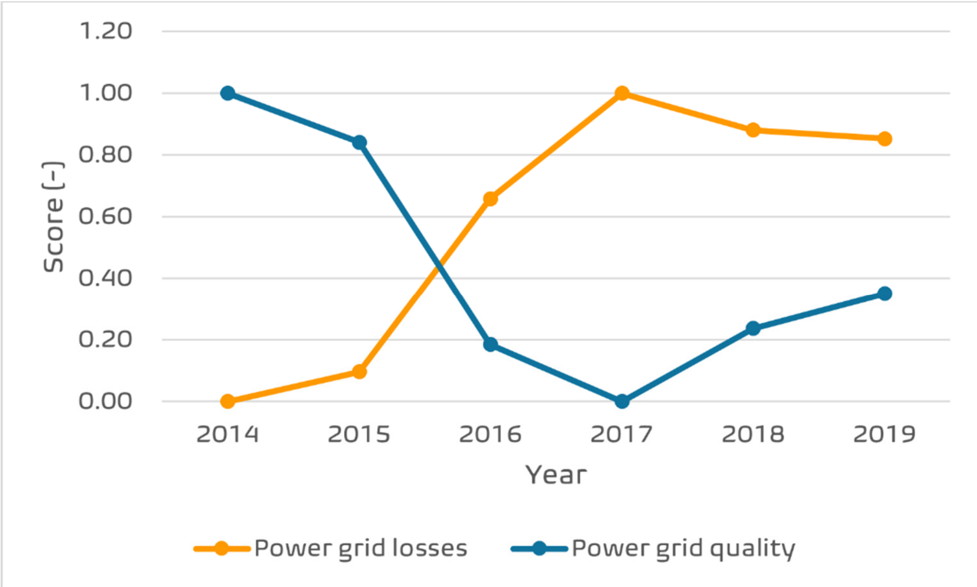

Figure 17. Normalized power grid quality and losses.

In relation to the grid integration of electric vehicles, instead, the number of electric chargers per electric vehicle (PG_{PEV}) has been increasing in the years; however, a larger effort to install further EV chargers is required given that less than a charger for EV is present in 2019 ($PG_{PEV} = 0.670$). Furthermore, the installation of new electric chargers has not been accompanied by installations of new renewable energy production systems (such PV) coupled with chargers as it can be seen by the trend of EV_{RES}.

3.4.3 Energy System – End-use sectors

For the analysis of final energy consumption in Turin city, it has been decided to consider the sectors: residential, tertiary, transport and other, excluding the industrial sector.
If for residential, tertiary and transport sectors data are collected by municipality, which is part of the Covenant of Mayors initiative, the other sector only takes into account public lighting. Data about agriculture, construction, waste and water management are not available.
Figure 18 shows the trend in energy intensity by population and gross city product (GCP), being this last one calculated as the sum of the incomes in the municipality.

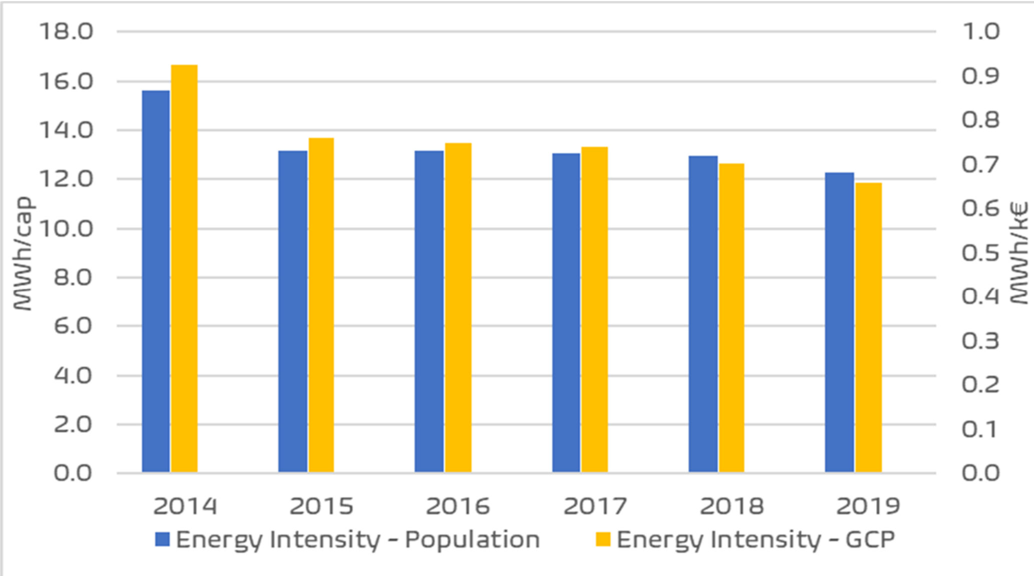

Figure 18. Energy Intensity by population and GCP (Data from [44]*,* [53]*,* [54]*).*

It can be observed that from 2014 to 2019, both energy intensity by population and GCP tend to decrease. In particular, the decrease in energy consumption by GCP seems to be quite important; this could be the result either of a variation in the economic structure of the city towards a low-energy intensity economy, or of a general improvement in energy efficiency.
Concerning the final energy consumption by sector, as shown in *Figure 19*, in 2019 the residential sector was the most impacting regarding energy consumption, followed by tertiary, transport and other; a general trend of reduction in energy consumption is present in each sector.

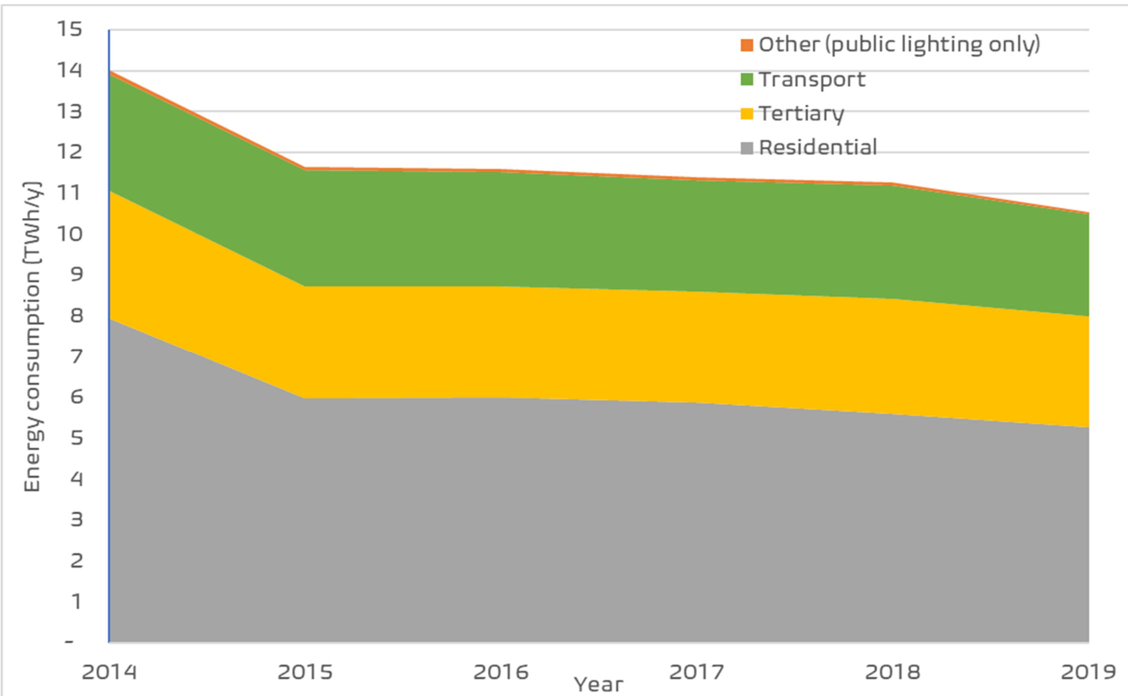

Figure 19. Energy consumption [TWh/y] by end-use sectors [44]*.*

In the following, a more detailed analysis of each sector is presented.

- **Residential**

In 2019, the residential sector was responsible of 5,266,222 MWh/y in final energy consumption, that is almost 50% of the final energy consumption in the municipality. By looking at the energy consumption by fuel mix, it is clear that the most of energy consumption is related to domestic heating, with natural gas and district heating covering about the 80% of residential energy consumption. However, from 2015 to 2019 it can be observed a general reduction of natural gas consumption, mainly thanks to improvements in energy efficiency and switching to district heating technology, whose consumption remains stable in the years (see *Figure 20*).

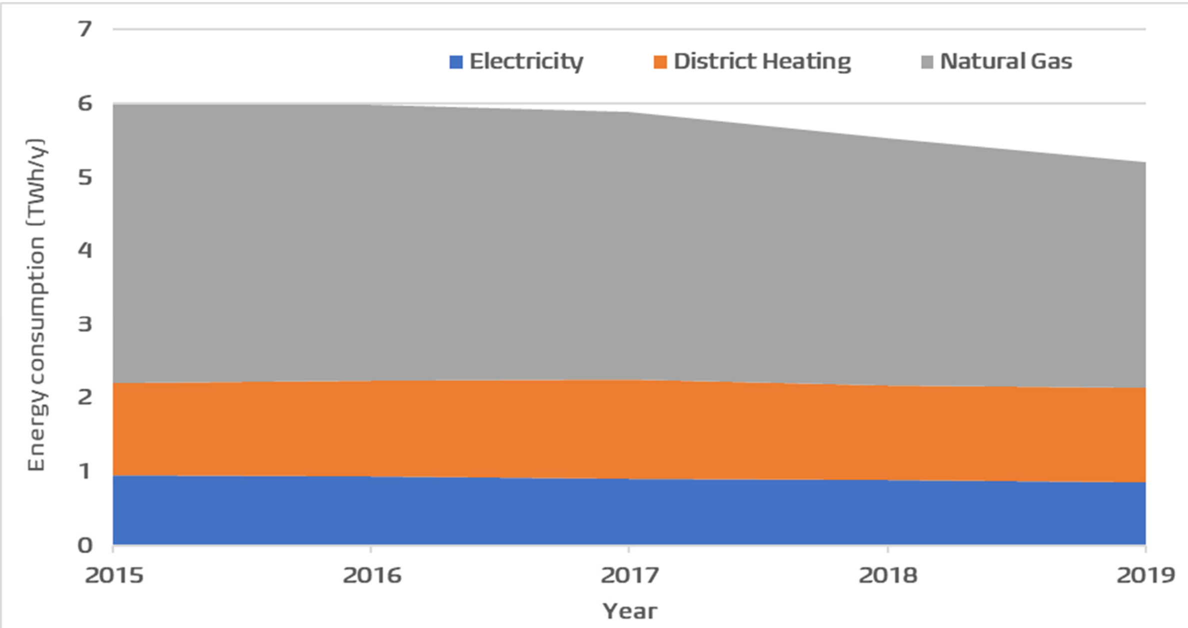

Figure 20. Residential energy consumption by fuel mix [44].

Given that domestic heating represents the most important cause of energy consumption in the residential sector, the climate-corrected energy intensity by floor area EIR_{RA} is crucial. To calculate this, the impact of temperature variations across the years by means of τ_{heat} is considered; then, data regarding the value of heating degree days from 2014 to 2019 are retrieved from the dataset of ARPA PIEMONTE; in particular, the amount of degree days for the winter season has been considered and calculated as the average of heating degree days of the measurement stations (Consolata, Vallere, Giardini Reali, Alenia). Then, the climate corrected energy consumption is evaluated, by imposing a value of $\sigma_{heat} = 0.7$ which corresponds to the ratio of final energy consumption for domestic heating and the final energy consumption in the residential sector [55]. Finally, values regarding total residential surface are retrieved from "Annuario Statistico – Settore Toponomastica ed Edilizia" provided by municipality, and EIR_{RA} is computed. The obtained results (*Figure 21*) show that energy intensity by floor area decreased from 2014 to 2019; similar trends are obtained for residential energy intensity by number of dwellings and population. As explained in chapter 2, whereas the former indicator can be used to explain trends in energy consumption for domestic heating/cooling, the last two indicators are proxy variables for energy consumption for lighting, appliances, and water heating: the decrease in all the three indicators could be interpreted as a signal of better performances (higher efficiency or wiser energy use) in all the kinds of final uses in the residential sector. Furthermore, energy consumption per dwelling decreases more than energy consumption per capita: this occurs due to the lowering of number of inhabitants per occupied dwelling, leading to higher energy consumption.

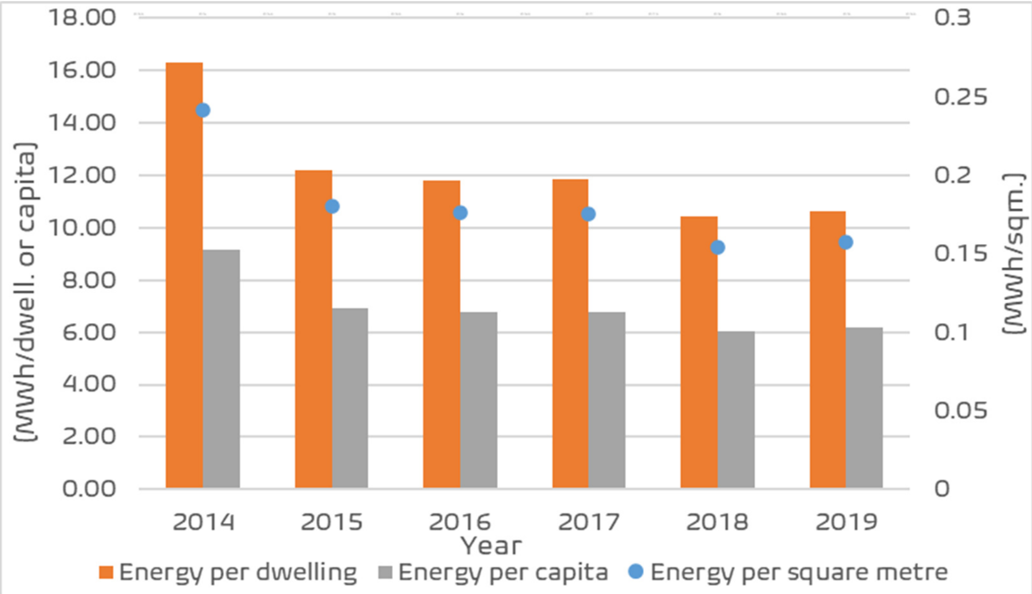

Figure 21. Climate corrected energy intensity in the residential sector.

Regarding additional supporting indicators developed for the residential sector, the only available data are the ones from the dataset "Dettaglio attestato di prestazione energetica (APE) - sezione impianti". The results for the fraction of analysed residences (almost 30% of the total number of residences) are reported in *Table* 20 and *Table* 21.

Table 20. Percentage of residential buildings supplied by fuel type for heating and HW production.

Fuel	Heating [%]	Hot Water [%]
Natural gas	63.2	65.10
District heating	30.56	4.64
Electricity	3.55	29.62
Oil	0.46	0.14
Solid Biomass	0.22	-
LPG	0.16	0.19
Solar Thermal	-	0.16

Table 21. Percentage of residential buildings by envelope performances

Envelope performance	Winter	Summer
Low	3.06	9.31
Medium	4.55	40.29
High	92.38	50.40

According to data regarding energy consumption, natural gas is the most spread fuel in residences, for both domestic heating and hot water production; on the other hand, dwellings supplied with electricity heating appliances (such heat pumps) still represent a small fraction of the total, showing a large margin for improvement, as for solar thermal generators of domestic hot water.
Concerning envelope performances in residential buildings, instead, the largest fraction of analysed buildings is equipped with high-performances envelopes, especially for winter season.

- **Transport**

Transport sector represents the third largest energy-consuming sector, amounting to 23% of the final energy consumption in 2019 [44].
The analyses carried out for the transport sector involve the passenger transport sector, being of primary importance in the context of municipalities. In particular, the following vehicles are included:

1. cars (electric, gasoline, diesel oil, LPG, methane)
2. public buses (electric, diesel oil, methane)
3. trams
4. metro

The four categories abovementioned, representing about the 54% of the final energy consumption in the transport sector, can be considered quite representative of this sector.
In the following, after the calculation of the indicators presented in 2.5.3, decomposition analysis has been applied to show the main drivers of change in energy consumption.
Concerning data availability, the values of energy consumption of public transport (bus, tram, metro) are yearly reported by the local public transport service GTT, whereas data regarding energy consumption of cars are contained in the dataset "TAPE", provided by municipality, as result of indirect calculation.
Distance travelled by passenger [pkm] for each class of vehicle, is also required to calculate energy intensity's indicators but since this information is not available, an alternative methodology is adopted. For private cars, the total yearly travelled distance D_{car} [km] is provided in dataset "TAPE" as a result of elaboration of traffic flux measurements by 5T; this one is then split by fuel type by equation:

$$D_{car,i} = w_{car,i} \cdot D_{car} \tag{3.3}$$

where $w_{car,i}$ represents the ratio between cars supplied with fuel i and the total number of cars in the city, and $D_{car,i}$ is the total yearly travelled distance by fuel i [km]. These values are retrieved from the dataset "Open Parco Veicoli" provided by ACI which distinguishes among the following car categories: gasoline, gasoline and gpl, gasoline and methane, full electric, diesel oil, hybrid electric & gasoline, hybrid electric & diesel oil. Hybrid cars can be further distinguished in HEV (hybrid electric vehicles), whose battery is recharged through regenerative braking and by the internal combustion engine, PHEV (plug-in hybrid electric vehicle) and REx (range extender vehicles). Given that only the last two categories have batteries which can be charged by connecting car to an external power input, and they represent a small fraction of hybrid cars sold [56], hybrid cars electric & gasoline are assumed to be gasoline cars, and hybrid electric & diesel oil cars are assumed to be diesel oil cars. Consequently, $D_{car,i}$ represents the yearly travelled distance by type of fuel i, where i belongs to the set ("Gasoline", "Diesel oil", "GPL", "Full electric", "Methane"). Once $D_{car,i}$ is calculated, the corresponding passenger distance $Pd_{car,i}$ is found by

$$Pd_{car,i} = D_{car,i} \cdot OR \tag{3.4}$$

where $OR = 1.3$ represents the occupancy rate of cars, set to a quite conservative value if compared with data in [57].

To benchmark the obtained values of energy intensity, gasoline cars are considered and compared with data provided in [58]. In 2019, energy intensity of gasoline private cars is equal to 2.9 MJ/pkm, a value a little bit higher than the ones provided in [58] (0.8-2.9 MJ/pkm). However, this can be explained by the fact that the chosen value of occupancy rate is quite low, as well as the fact that traffic congestion is responsible for increase in energy intensity, as also shown in [59].

Concerning public transport, instead, more approximations have been needed to create consistent time series for the scope of analysis.

For the year 2019, GTT provides data regarding the total distance travelled by passengers; this is then weighted with the number of available seats in each class of vehicles (tram, electric buses) whereas, for the methane and diesel oil buses, for which data regarding available seats were not available separately but only in aggregate form ($Se_{tr,fossilbus}$), a further weighting through the percentage of yearly travelled distance is applied (see (3.7)-(3.8)). The set of equations below shows the total passenger distance travelled by tram, electric buses, natural gas buses and diesel oil buses.

$$Pd_{tr,tram} = \left(Pd_{tr,urbp} - Pd_{tr,me}\right) \cdot \frac{Se_{tr,tram}}{\sum_{i=1}^{n} Se_{tr,i}} \tag{3.5}$$

$$Pd_{tr,elbus} = \left(Pd_{tr,urbp} - Pd_{tr,me}\right) \cdot \frac{Se_{tr,elbus}}{\sum_{i=1}^{n} Se_{tr,i}} \tag{3.6}$$

$$Pd_{tr,gasbus} = \left(Pd_{tr,urbp} - Pd_{tr,me}\right) \cdot \frac{Se_{tr,fossilbus}}{\sum_{i=1}^{n} Se_{tr,i}} \cdot \frac{D_{tr,gasbus}}{D_{tr,gasbus} + D_{tr,oilbus}} \quad (3.7)$$

$$Pd_{tr,oilbus} = \left(Pd_{tr,urbp} - Pd_{tr,me}\right) \cdot \frac{Se_{tr,fossilbus}}{\sum_{i=1}^{n} Se_{tr,i}} \cdot \frac{D_{tr,oilbus}}{D_{tr,gasbus} + D_{tr,oilbus}} \quad (3.8)$$

Where:

- $Pd_{tr,urbp}$ is the total passenger distance of urban public transport [pkm]
- $Pd_{tr,me}$ is the total passenger distance of metro, provided by GTT as separate value [pkm]
- $Se_{tr,i}$ is the total number of available seats for the vehicle i belonging to the set: trams, electric buses, natural gas buses, diesel oil buses [-]
- $Se_{tr,fossilbus}$ is the sum of number of available seats for diesel oil and natural gas buses [-]
- $D_{tr,oilbus}$ and $D_{tr,gasbus}$ are respectively the yearly travelled distances by diesel oil and natural gas buses [km]

For years from 2015 to 2018, similar approximations have been done, depending on data availability.
Values of energy intensity obtained for 2019 are coherent with values found in literature, as shown in *Table* 22.

Table 22. Energy Intensity for public transport (2019)

Energy Intensity [MJ/pkm]	Measured value	Literature value	Reference
Diesel oil bus	0.82	0.4 - 1.1	[58]
Natural gas bus	1.13	0.4 - 1.1	[58]
Electric bus	0.16	0.11 - 0.48	[60]
Tram	0.29	0.11 - 0.52	[60]
Metro	0.28	0.29	[61]

Figure 22 shows then the trend in energy intensity by class of vehicles.
First it should be noted that the aggregate energy intensity for the whole transport sector is decreasing; still, the value is more similar to energy intensity value of private cars, given that these represent the most used means of transport in the municipality.
If for metro and tram, energy intensity is quite stable in time, for public buses it can be observed a reduction of energy intensity which is the result of renovations of bus fleet. Concerning private cars, it is also observed a less clear reduction in energy intensity from 2015 to 2018, whereas from 2018 to 2019 energy intensity increases a bit due to changes in the car fleet from more energy efficient cars (diesel) to less energy efficient cars (gasoline).

Furthermore, the market share of electric cars is still quite low to provide important energy reductions in the transport sector (in 2019, only 0.12% cars were electric). Also, it appears clear that public transport is way more efficient than private transport.

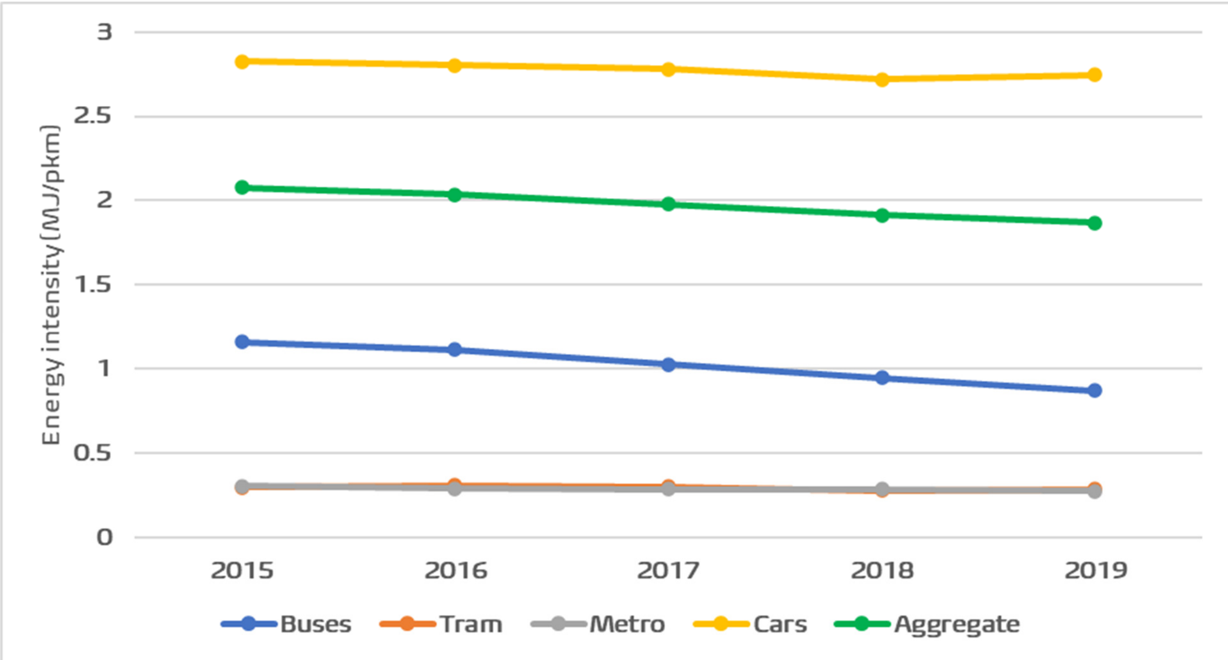

Figure 22. Energy intensity in transport sector by class of vehicles

To provide a more detailed view of the trends of aggregate energy consumption in the transport sector, decomposition analysis has also been applied. In this case, the analysed classes of vehicles are the ones of before, activity corresponds to the amount of yearly travelled distance by passengers [pkm], structure corresponds to the percentage of travelled distance by class of vehicles and fuel (methane bus, diesel bus, diesel car, gasoline car, …), and energy intensity is the ratio between energy consumption and activity [MWh/Mpkm].
Results are reported in *Figure 23*, and show year-to-year variations.
First, it can be observed a consistent trend of reduction in energy consumption due to variation in structure; this means that the amount of distance travelled by passenger with higher efficient means of transport increased. In particular, variation in structure is due to the fact that the percentage of distance travelled by means of public transport increased over years, as shown in *Figure 24*.

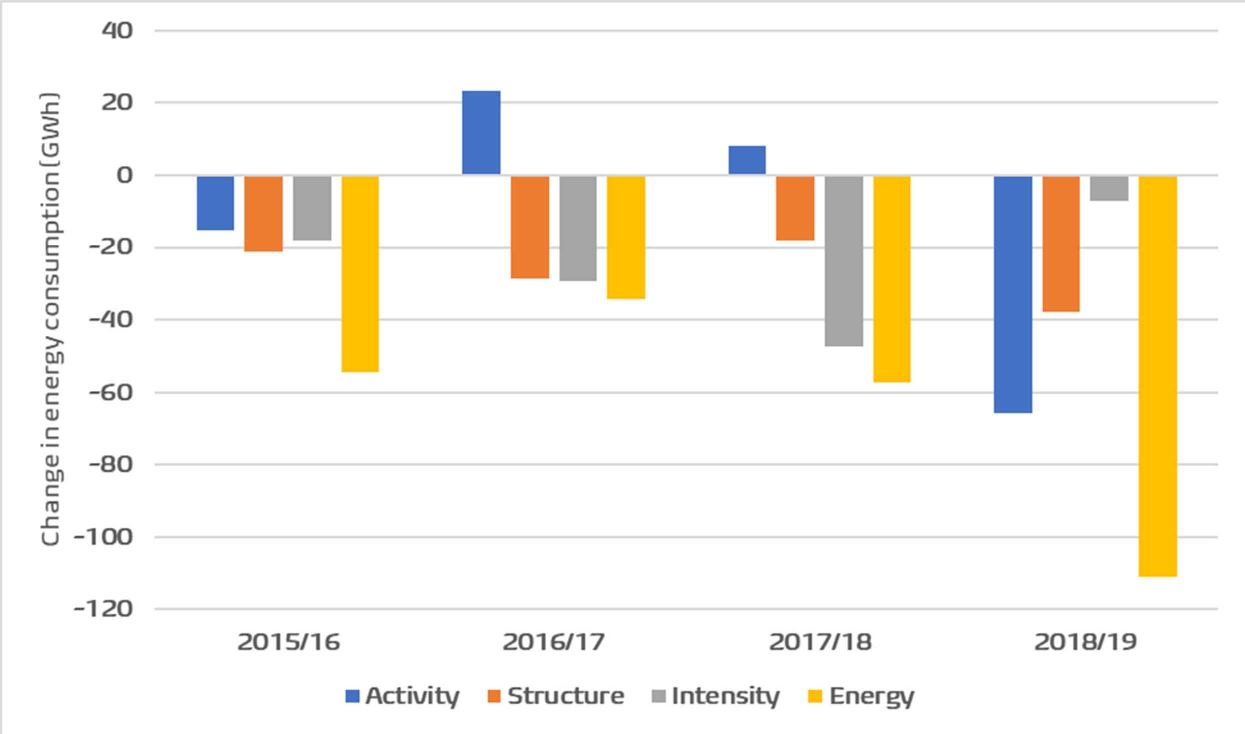

Figure 23. Energy consumption in transport sector – Decomposition

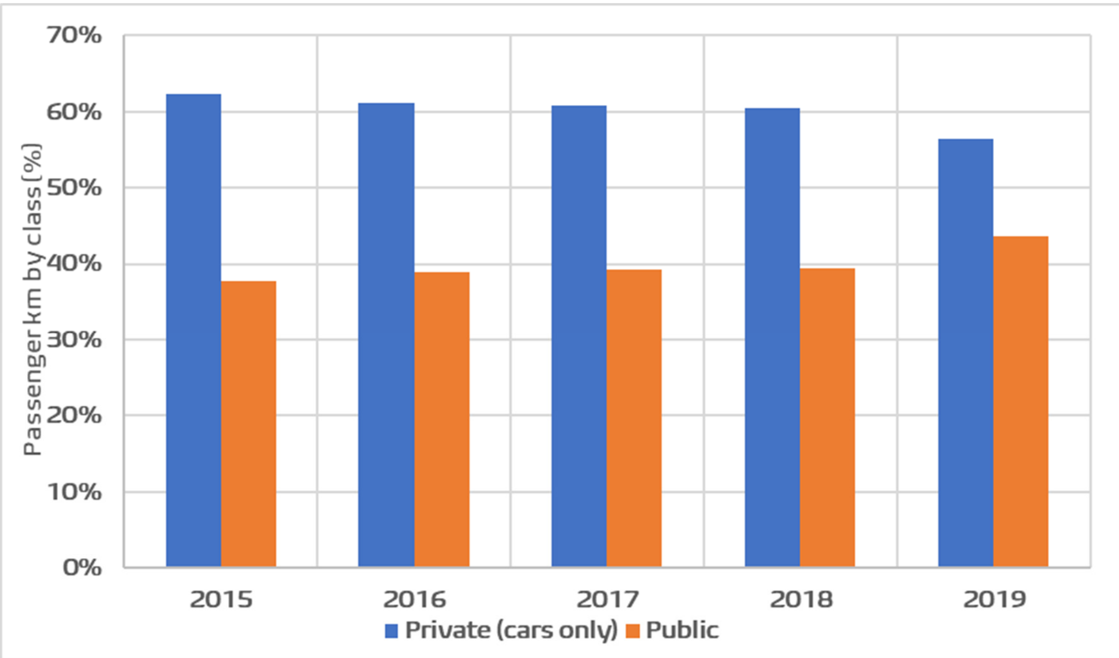

Figure 24. Percentage of travelled distance by passengers by class of vehicles.

Regarding variations in activity, the amount of travelled distance by passengers does not follow a particular trend in the years and it is driven by many causes (e.g. weather, proximity to work place, personal tastes…). However, it represents the main cause of reduction in energy consumption from 2018 to 2019. Finally, energy intensity positively contributes in all the years to the reduction of energy consumption as previously discussed.

Last set of indicators developed for the transport sector regards the environmental class (EURO) of private cars in the municipality. *Table 23* shows the European emission standards for diesel (gasoline) passenger cars for the various classes.

Table 23. European Emission standards for passenger cars [62]

Standard	CO [g/km]	NO_x [g/km]	PM [g/km]
EURO 1	2.72	-	0.14 (-)
EURO 2	1.0 (2.2)	-	0.08 (-)
EURO 3	0.66 (2.3)	0.50 (0.15)	0.05 (-)
EURO 4	0.50 (1.0)	0.25 (0.08)	0.025 (-)
EURO 5	0.50 (1.0)	0.18 (0.06)	0.005
EURO 6	0.50 (1.0)	0.08 (0.06)	0.0045

As it can be seen in *Figure 25*, the percentage of cars with EURO 6 classification had been steadily increasing from 2014 (5%) to 2019 (33.3%); however, the increase in the number of EURO 6 cars mainly occurred at the expense of EURO 5 cars (from 24.4% to 15.9%), whereas EURO 0 and EURO 1 cars only lost 0.6% of market share in the years.

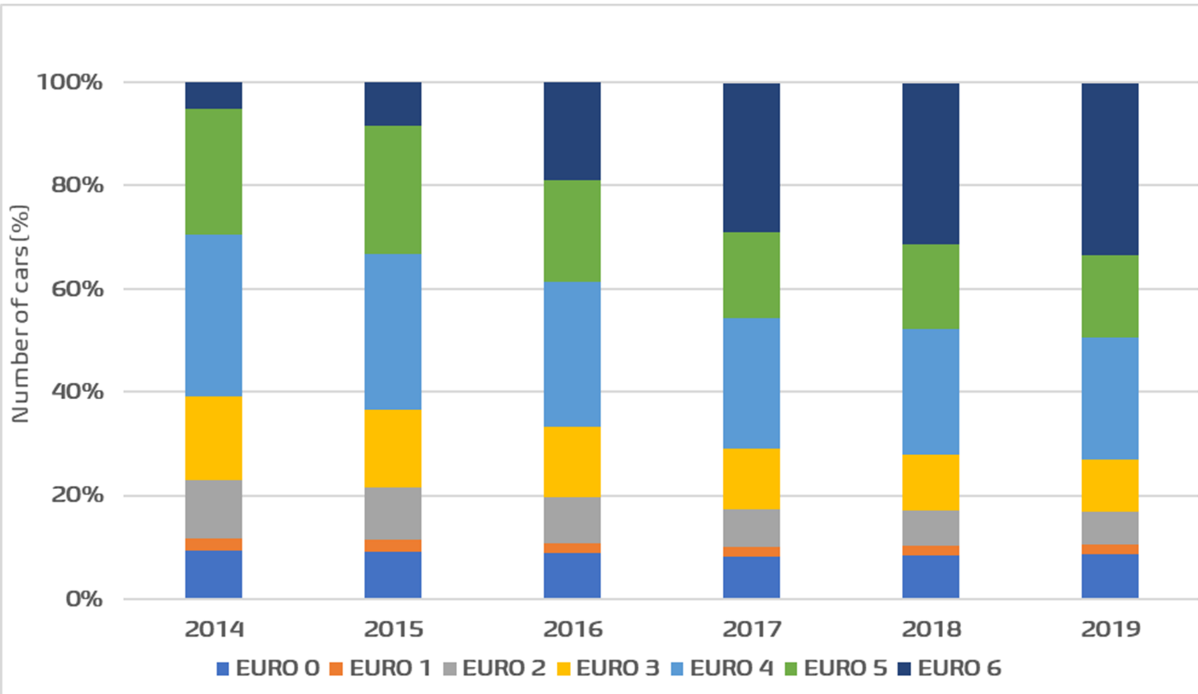

Figure 25. Percentage of cars by environmental classes (data from [63]*)*

- **Tertiary**

The tertiary sector, with almost 26% of final energy consumption of the city, is the second largest source of energy consumption.
The core indicator in this case is the energy intensity evaluated with respect to value added from the activities belonging to tertiary sector; this allows one to measure the relationship of energy consumption with economic development.
Data regarding energy consumption are provided in TAPE, whereas the amount of value added [M€] by typology of activity is retrieved in the dataset "Principali aggregati territoriali di Contabilità Nazionale - Valore aggiunto per branca di attività" by ISTAT. The economic activities considered for the analysis are the ones belonging to NACE classes from G to S, as data for the other economic activities belonging to tertiary sector (classes T, U) are not available. The results are shown in *Figure 26*.

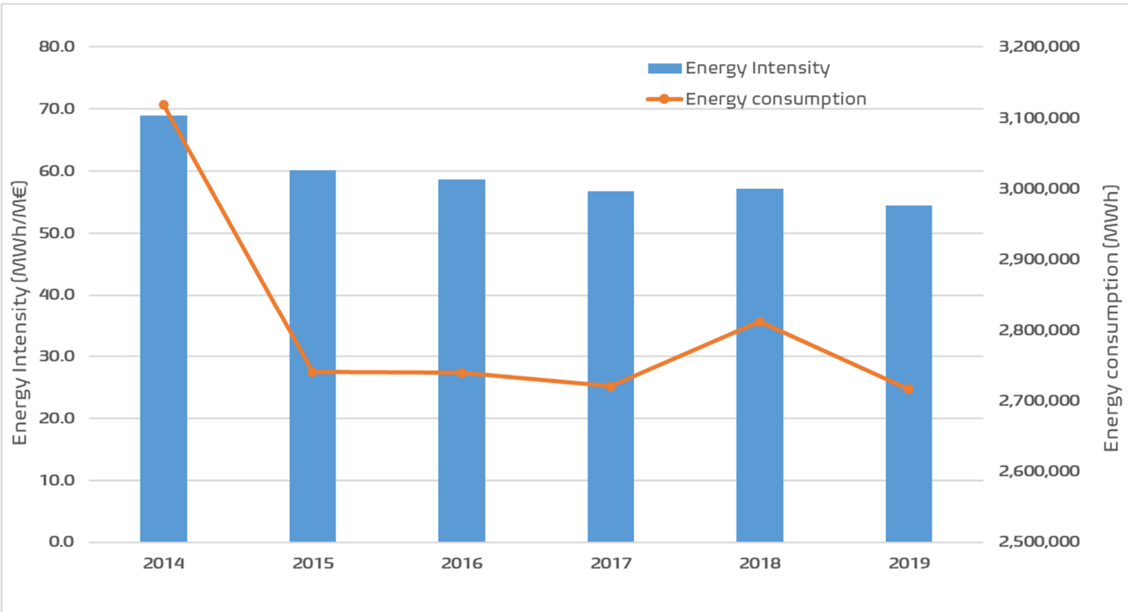

Figure 26. Energy Intensity in tertiary sector (data from [44], [54]*)*

Also in tertiary sector can be pointed out trends of reduction in energy intensity; the only exception occurs in 2018, when energy consumption increased a lot given the low winter temperatures. Furthermore, it can be observed that reductions in energy intensity are driven by decrease in energy consumption whereas economic activity [M€] whereas remains quite stable in time.
Decomposition analysis was applied again to further understand trends in variations of energy consumption. In this case, activity represents the amount of value added [M€], structure is the percentage of value added by class of activity and energy intensity is the ratio between energy consumption and the amount of value added.
Unfortunately, data were only available for accounting changes in the years 2015-2016 and 2016-2017. *Figure 27* shows the results.

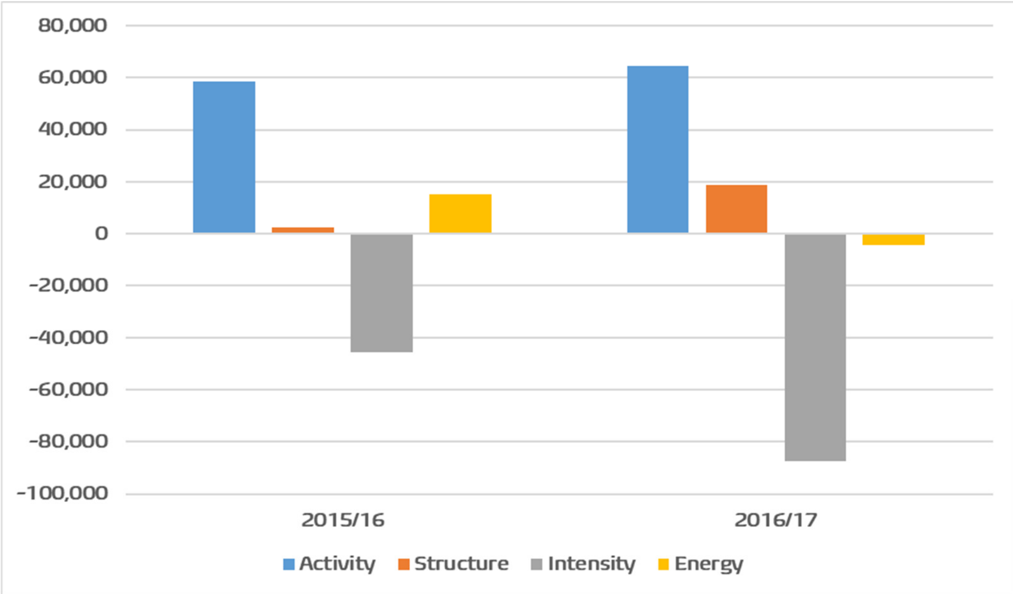

Figure 27. Decomposition analysis in the tertiary sector

Decomposition analysis confirms that, for the analysed years, changes in energy consumptions are mainly driven by the increase in the total amount of value added and changes in structure which seem to show a migration towards more energy intensive activities. Energy intensity decreases as a signal of improved efficiency.

- **Other**

The "Other" sector comprises data regarding public lighting, water and waste management and the "construction" class of activity. For the present analysis, only energy consumption values of public lighting were available, despite data about water and waste management that are not included. In particular, concerning the water management integrated service, data were provided for the whole area served by the local utility SMAT but not separated for Turin municipality. On the other hand, evaluating energy consumption in waste management process is even more complex, as data are both sparse and partial. Total energy consumption in waste management involves indeed the evaluation of energy consumption from:

- waste collection
- waste transportation
- waste disposal

as well as the amount of energy consumed in buildings related to waste management service. These kinds of data were not available and, furthermore, quantification of energy consumption due to waste transportation and disposal is particularly difficult due to the necessity of tracking waste produced in the municipality until the various waste disposal centres.
Given these premises, indicator of energy intensity in water management is referred to the whole area served by SMAT and energy intensity in solid waste management is calculated as

the ratio between total consumed energy in the main waste disposal plant of the Turin municipality (Gerbido waste incinerator) and the amount of waste treated by the plant. Indicators of the other sector are reported in *Table* 24.

Table 24. Indicators of the "other" sector

Indicator	2014	2015	2016	2017	2018	2019
EIPl [MWh/lights]	0.89	0.92	0.70	0.55	0.60	0.59
EIW [MWh/t waste]	0.221	0.214	0.229	0.199	0.181	0.173
EIWat [kWh/ab eq.]	132.2	132.5	133.6	134.5	135.2	131.4

Energy intensity for public lighting has a fluctuating behaviour, but is generally decreasing, mainly thanks to the adoption of LED lights by public administration.
Also, energy intensity in solid waste disposal has been decreasing whereas the opposite occurs for water management service until 2018, while in 2019 higher energy efficiency seems to be reached.

3.4.4 Environment – Resources

Indicators in the "resources" subdomain regard the fields of waste, water and land use.

- **Waste**

The analysis of the *Waste* field involves special and urban waste produced inside the municipality boundaries.
Special wastes are mainly managed by private companies and, because of that, tracking the process from waste generation to final disposal is quite difficult. The only available data, in this case, concern yearly special waste generation and are the result of elaborations made by ARPA PIEMONTE on MUD, the module used for communicate the produced and/or managed wastes from economical activities, waste collected and disposed, recycled and transported by municipalities. Producers of special waste must compile MUD for legal obligations.
Concerning urban waste, Turin municipality is part of the "Consorzio Bacino 18" (now "CAV Torino") which manages, through the society AMIAT, the cycle of urban waste.
As reported in [64], AMIAT's politics of waste disposal is to realize circular economy, by recovering energy and/or materials from the urban waste collected in the city. In particular, the recyclable fraction of urban waste is treated, for the most part, by plants managed by AMIAT and societies of IREN group (plastic, RAEE, bulky waste, paper, OFMSW) whereas the remaining part is sent to other plants for recycling.
Non-recyclable fraction of waste, instead, is sent to the Gerbido waste incinerator, producing both thermal and electrical energy.

As it can be seen from *Figure 28*, the percentage of recyclable urban waste has increased in the years whereas the total generation of urban solid waste is quite constant. On the other hand, the production of special waste has been increasing a lot, highlighting the need for dedicated facilities for the sustainable disposal and/or recovery of materials.

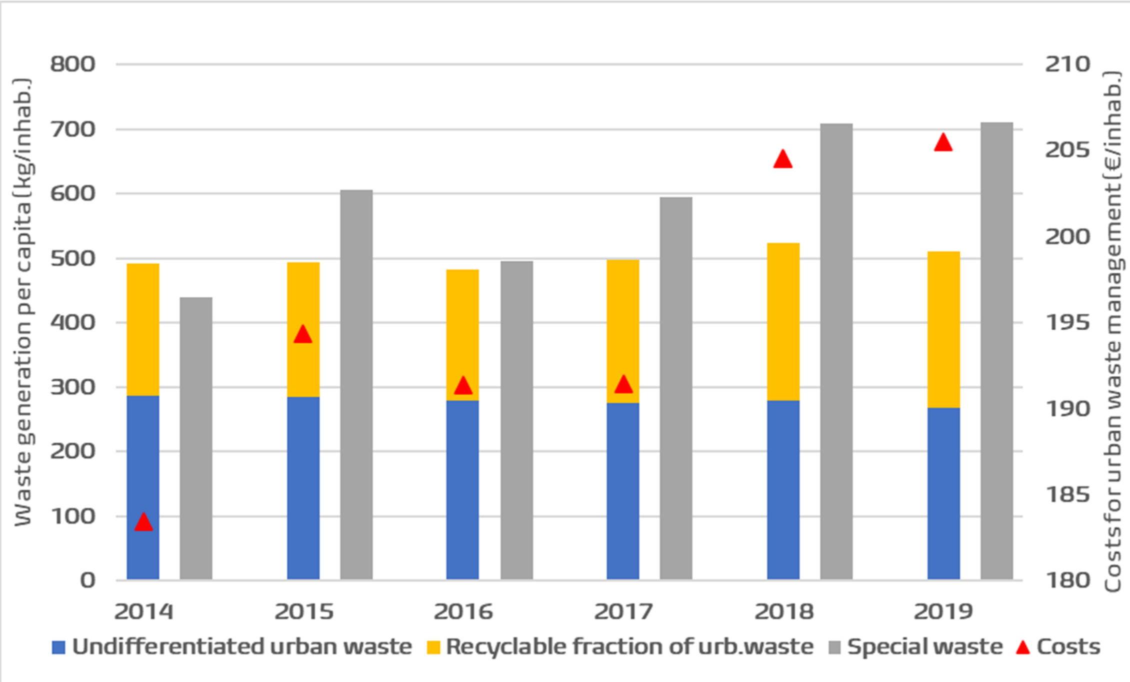

Figure 28. Waste generation and costs per capita in the municipality [65]–[67]

The increase of the percentage of recyclable fraction of urban waste (from 42.4% in 2014 to 50.8% in 2019) had also an impact on the expenditure on waste management per capita which have been increasing in the years due to increases in costs for management of differentiated waste (CGD), and, in particular, due to higher costs for treatment and recycle of materials (CTR).
The other indicators of the set defined in 2.5.4. regard gross energy generation per quantity of treated waste (WEG), the number of exceedances of limits for atmospheric/water pollution in waste disposal process and the amount of GHG emissions per quantity of treated waste (GHG_{WASTE}).
Concerning these indicators, among waste disposal facilities, it has been decided to only consider waste incinerator plant in Gerbido, whereas the landfill "Basse di Stura" is not accounted for, given that it is not used anymore for waste disposal, and data on the recycling waste facilities are missing.
Furthermore, given that data regarding GHG emissions arising during the phases of waste collection and transportation are not available, GHG_{WASTE} has been only evaluated with respect to waste incinerator plant.
Given that the waste incinerator treats almost 50% of the urban waste, the found results, reported in *Table* 25, can be considered valid in first approximation.

Table 25. Other indicators in the "waste" field

Indicator	2014	2015	2016	2017	2018	2019
WEG [MWh/t_{waste}]	0.701	0.745	0.774	0.777	0.748	0.761
GHG_{waste} [t_{CO2EQ}/t_{waste}]	-	-	-	1.05	1.04	1.03
PAH emissions[7] [ng/Nm^3]	1.497	0.497	0.233	0.470	0.160	0.077
Dioxins emissions [pg/Nm^3]	0.887	0.183	0.153	0.411	0.134	0.059
Number of half-hours with overrunning [-][8]	287	133	48	41	46	8

Energy generation from waste remains quite stable in time, slightly increasing from 2014, and the same holds true for the amount of GHG emissions produced by the waste incinerator.
With respect to atmospheric pollution, it can be observed an improvement of environmental performances. To evaluate these, not only it has been considered the number of half-hours with overrunning of the limits for HCl, CO, NO_x, SO_2, COT, fine dusts, HF and NH_3, but, also, the amount of emissions of PAH and dioxins which are two of the main pollutants produced by waste incineration process. In particular, dioxins are responsible for skin diseases and damages to immune system, whereas PAH can cause cancers and create other kinds of diseases (i.e. respiratory and gastrointestinal). Looking at the indicators, for both the pollutants, safety limits are always respected (for PAH the limit is 10,000 ng/Nm^3 and for dioxins is 100 pg/Nm^3) and, also, reduction in total pollutant emissions are accomplished.

- **Water**

In relation to the management of integrated water service, Turin municipality is part of "Ambito territoriale ottimale ATO 3 Torinese", an association of 307 municipalities, all comprised in the territory of the Turin metropolitan area. The management of water integrated service is assigned to SMAT, whose social capital belongs for the 64% to Turin municipality. In 2021, SMAT manages 288 municipalities and 2,199,854 inhabitants, of which 39% belongs to Turin municipality. Given that no data split by municipality was available, the indicators refer to the whole territory served by SMAT which, in first approximation, can be considered representative for Turin municipality.
The values of indicators for the main phases of urban water cycle, presented in 2.4.4, are reported in *Table* 26.

[7] Indicators of PAH and dioxins emissions are calculated as the average of the values of the three operating lines of Gerbido waste incinerator

[8] The indicator is calculated as the sum of the number of half-hours with overrunning for each of the three lines of Gerbido waste incinerator

Table 26. Main indicators in the "water" field

Indicator	2014	2015	2016	2017	2018	2019
$Wa_{,qual}$ [%]	99.99	99.98	99.99	99.97	99.98	99.99
$Wa_{,par}$ [-]	264	271	290	308	325	304
$Wa_{distr,loss}$ [%]	22.40	24.60	24.70	24.60	25.00	22.20
$\overline{W}$ [l/ab day]	293	292	288	288	286	279
$Wa_{tr,pop}$ [%]	98.8	98.7	98.7	98.8	98.5	99.4
$\eta_{wa.tr_{SST}}$ [%]	92	96	97	98	98	98
$\eta_{wa.tr_{BOD}}$[%]	97	98	98	97	98	97
$\eta_{wa.tr_{COD}}$ [%]	91	95	95	96	96	91
$\eta_{wa.tr_{N}}$ [%]	70	73	76	76	76	70
$\eta_{wa.tr_{P}}$ [%]	82	86	82	82	81	82

Indicators in the supply phase of water integrated cycle show that the quality of water immitted in aqueducts is perfectly compliant with limits in DL 31/2001; furthermore, the increasing number of inspections is signal of higher reliability of the results.
Distribution losses in water aqueduct increased from 2014 to 2018, even if best results for the analysed period are achieved in 2019. The indicator of distribution losses, contrary to the other ones, is directly referred to Turin municipality.
Average daily consumption of water by inhabitant has consistently decreased in the years, testifying better habits of citizens, and the percentage of population served by wastewater treatment systems (even if already high) has increased, implying less risks of pollution.
Concerning quality standards for water discharge, it has been reported the value of removal efficiency for the purifier plant located in Castiglione Torinese, which treats most of the wastewater produced in Turin. The plant is, as testified by the reported values, very efficient in removing pollutants; if compared with limits values shown in *Table* 27, the related CWD for all the parameters is always equal to 100%, therefore removal efficiency is always equal or higher to the one prescribed by law.

Table 27. Limit values of removal efficiency for wastewater treatment plants serving more than 10,000 equivalent inhabitants [68]

Indicator	Minimum removal efficiency
SST	90%
BOD	80%
COD	75%
N	70-80%
P	80%

Other, cross-sectoral, indicators of the *water* field consider relations with *waste*, *GHG* and *air pollutants* fields.
In relation to *waste* field, it has been evaluated the percentage of recycled non-hazardous waste produced in water integrated service. This has been increasing from 2014 to 2019, reaching almost 100% of recycling rate.
Concerning *GHG* field, the evaluation of the indicator GHG_{water} requires the calculation of the total greenhouse gases emissions produced in the water cycle.
To do this, it has been used the emission inventory produced by SMAT in the dataset "Bilancio di Sostenibilità". With the aim of building an historical series which is consistent with the normalization procedure needed to build indexes, only scope 1 and 2 non biogenic emissions have been taken into account (whose data are available from 2012). In particular, among Scope 1 emissions, values of emissions due to stationary combustion for industrial uses and heating of buildings, mobile combustion, process emissions and fugitive emissions are reported. Process emissions are due to biological treatment, anaerobic stabilization and denitrification of sludges separated from wastewater, as well as ozonisation of potable water, and they represent a consistent fraction (about 65%) of scope 1 emissions. However, they have only be reported from 2019; consequently, the 2019 value has been also assumed for the previous years. Indirect emissions, instead, take into account methane leakages from cogeneration engines and from deodorization plants. Scope 2 emissions are the ones produced by thermal and electrical energy consumption in SMAT buildings.
It has to be noted that from 2020 SMAT has changed the calculation method of total GHG emissions produced, in light of the revised 2019 IPCC methodology, and now also accounts for Scope 3 emissions, as well as the quantity of GHG subtracted from atmosphere thanks to various eco-sustainable initiatives. This has the purpose of evaluating the carbon footprint of the company, and, in the future, it could be a more reliable measure of the indicator GHG_{water} provided here.
Regarding the *air pollutant* field, the total emission of CO, NMVOC, fine dust, NO_X, SO_X, and NH_3 produced in the cycle of water integrated service are evaluated and normalized with the equivalent population.
Table 28 reports the calculated cross sectoral indicators in the *water* field.

Table 28. Cross sectoral indicators in the "water" field

Indicator	2014	2015	2016	2017	2018	2019
$\eta_{water,nhw}$ [%]	89.4	94.1	94.2	99.36	99.06	99.58
GHG_{water} [tCO2eq/in.]	54.5	46.7	45.6	43.4	43.8	18.2
$AP_{water,finedust}$ [kg/in.]	654.94	637.63	550.87	512.45	581.10	491.49
$AP_{water,SOx}$ [kg.in.]	1,280.85	1,445.34	773.43	1,160.98	1,370.44	1,583.04

$AP_{water,CO}$ [t/in.]	14.08	8.81	3.54	3.99	4.89	4.91
$AP_{water,NOx}$ [t/in.]	19.35	20.27	14.60	19.50	15.57	17.87
$AP_{water,NMVOC}$ [t/in.]	33.87	34.37	10.62	11.97	8.01	10.72
$AP_{water,NH3}$ [kg/in.]	33.43	48.47	34.51	104.62	48.50	42.00

First, it can be observed a positive trend in reduction of GHG emissions, with an important decrease from 2018 to 2019. This is due to the consistent reduction in scope 2 emissions, obtained thanks to the choice of SMAT society of buying 80% of electrical energy from renewable sources, whose emission factor is considered to be null.
Concerning the amount of emissions of air pollutants, an important trend of reduction is observed for CO and NMVOC, whereas the others remain stable in time except for SO_x emissions, which increased a lot in 2019.

- **Land use**

Main source of data for developing indicators of the "land use" field is ISPRA, which provides both the indicators of consumed soil per capita and urban dispersion index. *Figure 29* testifies that no large changes in land use occur during short periods as the one of analysis. The amount of consumed soil per capita lightly increased, because of the increase in the built-up area accompanied by an opposite trend in the amount of population, and the same occurs for green surface which has slightly increased from 219 ha/100,000 inhab. to 226 ha/100,000 inhab.
The urban dispersion index assumes very low values if compared with other Italian cities [69] and even reduces in time, indicating that the municipality is quite compact and mainly characterized by highly populated areas.

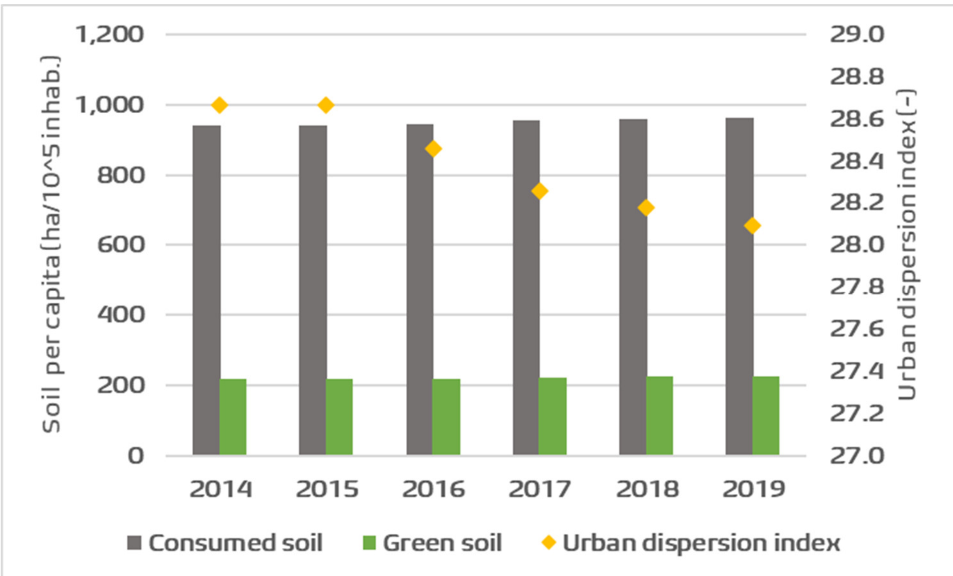

Figure 29. Main indicators in the "land use" field ([22], [53])

Urban pedestrian areas and bike lanes have been increasing as well, as shown in *Figure 30*.

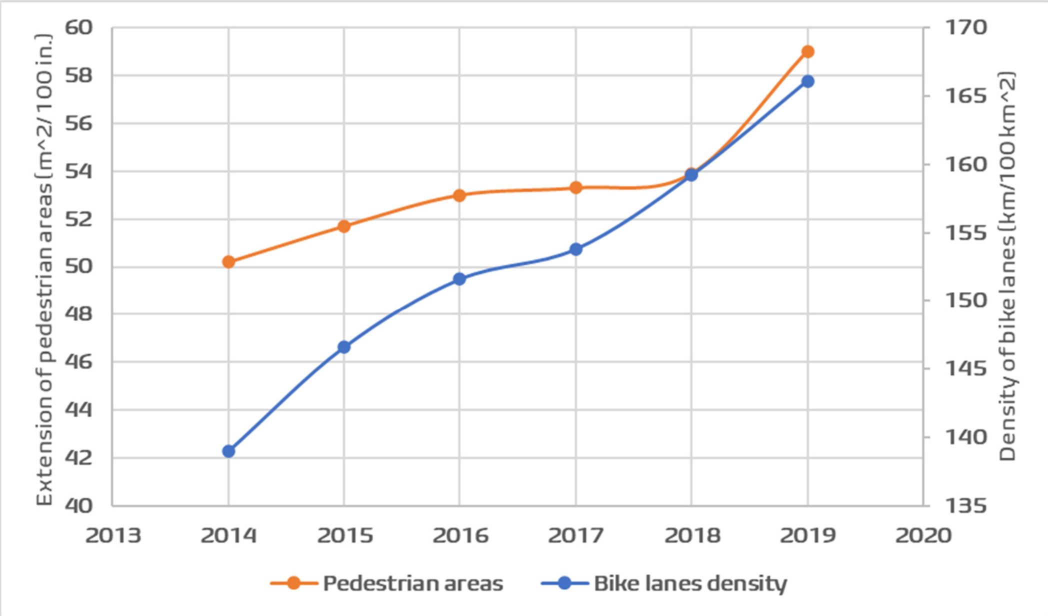

Figure 30. Urban pedestrian areas and bike lanes. [71]

3.4.5 Environment – Emissions

- **Air pollutants**

To evaluate the concentration of air pollutants, data collected from measurements stations installed in the municipality have been used. In Turin, there are 5 measurement stations (*Figure 31*); two of them (Rubino, Lingotto) are background stations whereas the others (Consolata, Rebaudengo, Grassi) are traffic stations. The difference between the two typologies lies in the fact that, if the first type is used to measure levels of pollution which are not influenced by discrete pollution sources, the latter allows to measure the impact of vehicular traffic on air pollution.

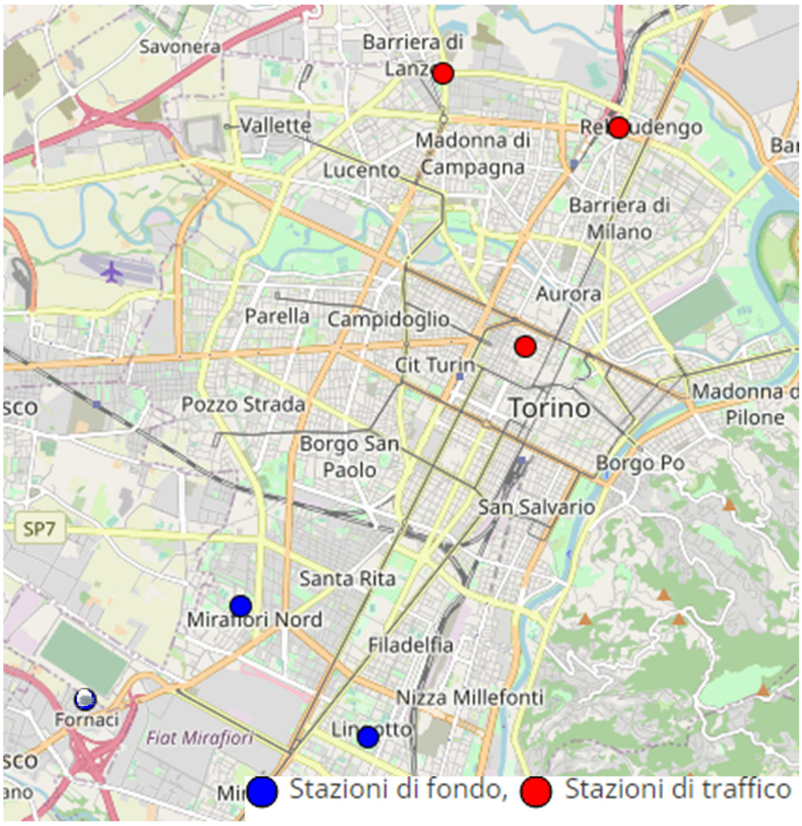

Figure 31. Air pollution measurement stations in Turin

For developing the indicators presented in 2.4.5, only background stations have been considered, measuring the integrated effect of the various sources of air pollution.
The obtained indicators (*Figure 32*), are calculated as the average of the measurements of the two background stations; data are retrieved from the dataset "Aria – la qualità dell'aria in Piemonte".

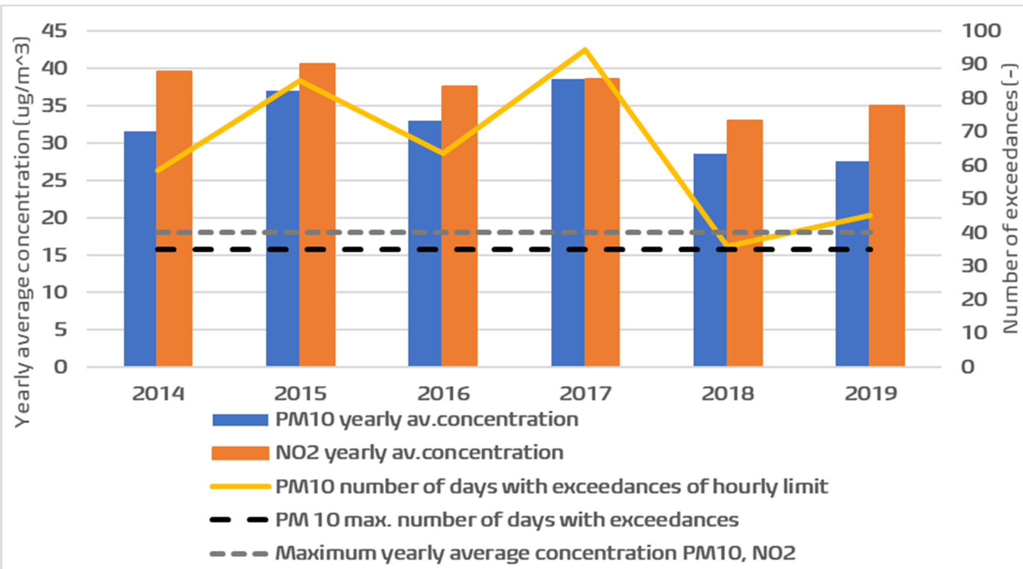

Figure 32. PM10 and NO_2 indicators [72]

Both PM_{10} and NO_2 air pollutants always exceed the thresholds, presented in *Figure 9*, regarding the maximum yearly average concentration and, in the case of PM_{10}, also the threshold of number of daily exceedances in a year. However, in the last years the number of PM_{10} daily exceedances moderately decreased, also satisfying the limit in 2018.

- **GHG**

To account for total GHG emissions in the municipality, data of energy consumption and emission factors by fuel provided in the dataset [44] have been used. Values of emission factors are reported in *Table* 29 for 2019 year.

Table 29. Emission factors for energy carriers in 2019

Energy carrier	Emission factor [t_{CO2}/MWh]
Electricity	0.439
District heating	0.161
Natural gas	0.202
LPG	0.231
Fuel oil	0.279
Diesel oil	0.267
Gasoline	0.249

The lowest emission factor is the one of district heating, followed by natural gas, while electricity emission factor is the highest one among analysed energy carriers. This results from the fact that the assumed national emission factor for electricity (NEEFE) of 0.483 t_{CO2}/MWh is outdated and currently overestimates the amount of CO_2 emissions from electricity. In fact, thanks to increasing installations of renewable energy capacity, the NEEFE has been decreasing in the years; for example, [73] reports a value of 0.344 t_{CO2}/MWh in 2013 for Italy. Unfortunately, as no data were available for evaluating AEV and CO_2AEV in (2.35), the local emission factor for electricity has not been modified, and analysis in the following are carried out with the value in *Table* 29.

At the present time, only CO_2 emissions are evaluated, and categorized by the sectors considered in paragraph 3.4.3, which represent a subset of the sectors of emissions presented in 2.5.5. In particular, emissions from wastewater treatment, changes in land use and from industry are not taken into account here due to data unavailability, whereas emissions arising from solid waste management are taken into account only partially, by considering the non-recyclable fraction of waste disposed in Gerbido waste incinerator (data regarding emissions

from waste recycling are not present). This kind of emissions is included, together with the ones arising from public lighting, in the “other” sector.
Figure 33 shows trends in CO_2 emissions by sector.

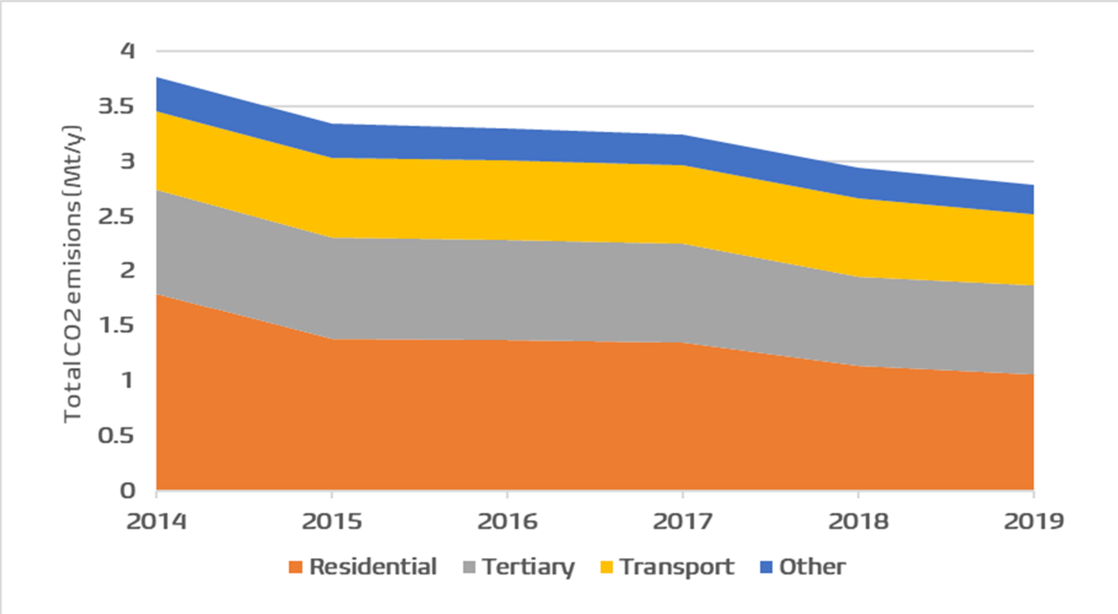

Figure 33. CO_2 emissions by sector [44]

From 2014 to 2019 CO_2 emissions have been consistently decreasing, starting from the value of 3.77 Mt/y and reaching 2.61 Mt/y in 2019. The main source of CO_2 emissions, being the largest responsible for energy consumption, is the residential sector, contributing for the 33.5% in 2019, and followed by tertiary (31.0%), transport (24.7%) and other (10.8%) sectors.
However, the residential sector has been the most CO_2-cutting sector with a reduction in emissions of about 0.9 Mt in 6 years.
To better understand the drivers of change in CO_2 emissions in the residential sector, decomposition analysis has been used. In this case, variation in activity depends by energy consumption [MWh], variation in structure is dependent by energy consumption by type of fuel [%], whereas changes in emission factors provokes variations in intensity. Of course, changes in emission factors are only possible for local emission factors (electricity and district heating) and are related, in the case of electricity, to added installed capacity of renewable energy and/or purchases of green electricity by local administration, whereas, in the case of district heating, they depend on performances of heat-producing plants (“Centrale Torino Nord”, “Centrale Moncalieri”).
For the present analysis, only electricity, district heating and natural gas are considered as energy commodities, given that data regarding consumption of other fuels are missing for certain years in the analysed time span; furthermore, data regarding local emission factors in 2015 and 2016 were missing as well, and consequently, 2017 values have been adopted for these years. *Figure 34* shows the results.

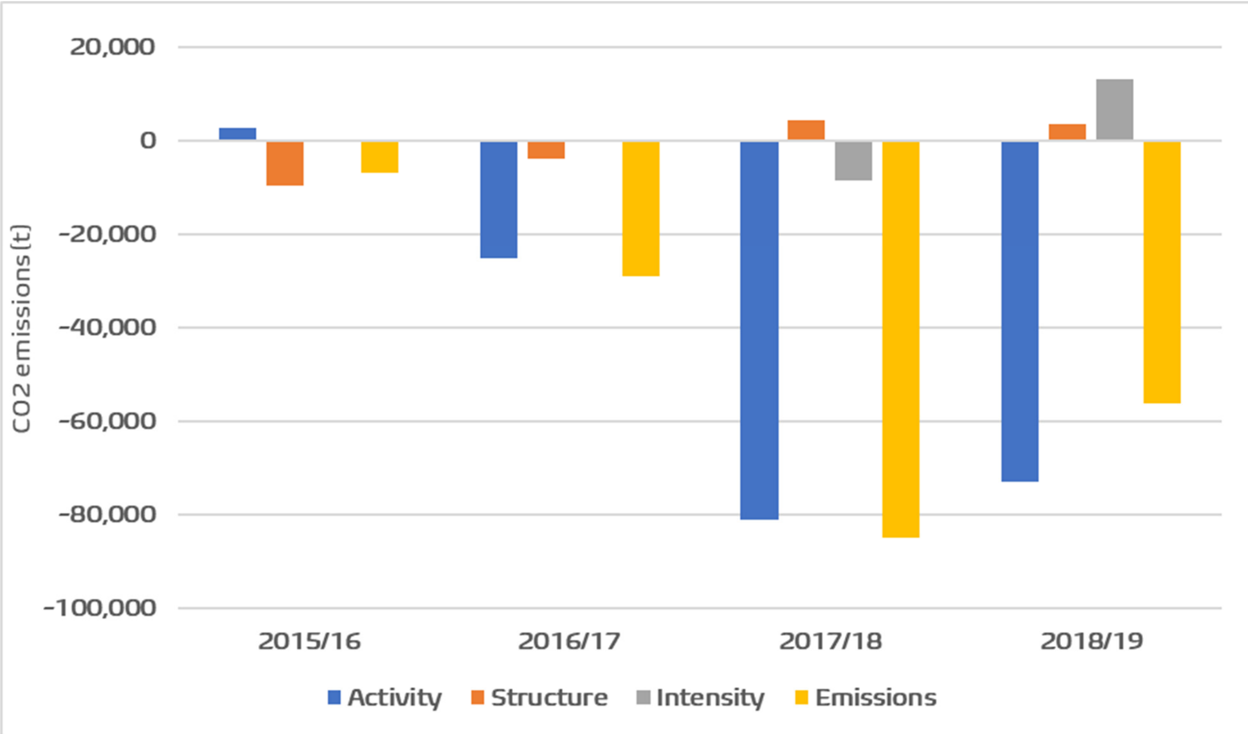

Figure 34. Decomposition analysis for CO_2 emissions in residential sector.

It can be observed that reduction in CO_2 emissions has been driven by reduction in energy consumption from 2016, whereas the effect of structure and intensity variations from 2018 to 2019 have not been beneficial. Negative changes in structure depend by the fact that consumption of electricity (which has the highest emission factor) has become more relevant on total energy consumption, increasing from 15.5% in 2017 to 16.4% in 2019, whereas the negative changes in intensity from 2018 to 2019 are related to the increase of the local emission factor for district heating from 0.150 t_{co2}/MWh to 0.161 t_{co2}/MWh.
On the other hand, a beneficial effect on the reduction of CO_2 emissions in the years has been brought by the switching in heating technologies from natural gas-based burners to district heating technology, and this is evident, especially in the first years of analysis, when the structure variation positively contributes to reduction of CO_2 emissions.

3.4.6 Socio/Economy - Wealth

As already explained in the second chapter, the analysis of the *wealth* subdomain is focused on the evaluation of the themes related to the energy and environmental spheres which are energy poverty, jobs and value added and investments.

- **Energy poverty**

Developing indicators $EP\eta_2$ and $EP\eta_3$ in this field requires data regarding expense of families in the municipality, which are not available as shown in 3.3. Consequently, the analysed

indicators are calculated for the whole Piemonte region, for which data are provided in "Indagine sulle spese delle famiglie: microdati ad uso pubblico" by ISTAT. The dataset contains the results of questionnaires yearly taken by ISTAT to analyse the expenses of families in Italy, which are evaluated by means of 1,323 variables. Among these, all data needed for building the indicator $EP\eta_2$ are present, whereas in the case of indicator η_3 data on the presence/absence of expense for heating are missing and it is not calculated.
For indicator $EP\eta_2$, the energy expense has been calculated as

$$s_{ie} = B5_{bf} + B10_{bf} + B27_{bf} + B30_{bf} + B59_{bf} + B63_{bf} + B67_{bf} + B71_{bf} \qquad (3.9)$$

where:
- $B5_{bf}$ is the expense for electric energy [€]
- $B10_{bf}$ is the expense for natural gas [€]
- $B27_{bf}$ is the expense for central heating [€]
- $B30_{bf}$ is the expense for district heating [€]
- $B59_{bf}$ is the expense for butane [€]
- $B63_{bf}$ is the expense for heating oil, kerosene and other liquid fuels [€]
- $B67_{bf}$ is the expense for coal [€]
- $B71_{bf}$ is the expense for solid biomass [€]

Values of the indicator $EP\eta_2$ [%] for the analysed time span are reported in *Figure 35.*

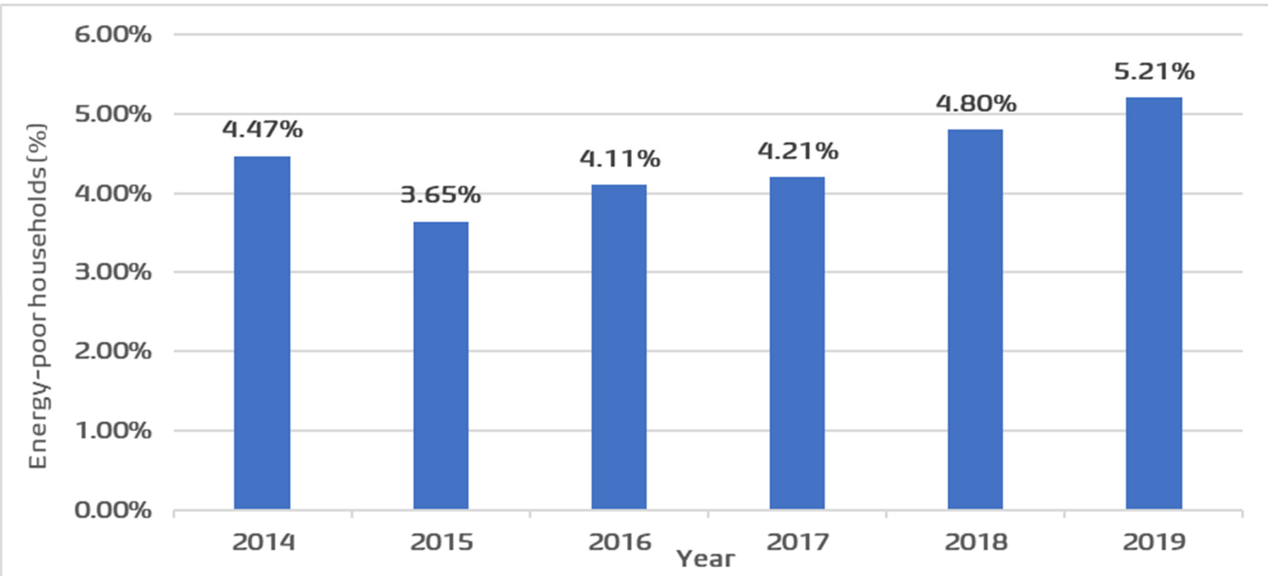

Figure 35. Energy poverty ($EP\eta_2$) in Piemonte (data from [74]*)*

From 2015 to 2019, the percentage of families in energy poverty in Piemonte region has been continuously increasing, reaching 5.21% in 2019. This trend is justified by the fact that the percentage of families in relative poverty has increased as well in the years (from 6.0 to 7.5% in the period 2014-2019), causing more and more families to invest a larger fraction of their income in energy expense.

- **Jobs, value added and investments**

The last set of indicators regard the fields of "Jobs & Value added" and "Investments in E&E". As shown in *Figure 36*, value added produced by activities of NACE classes D and E has increased in the years, with an improvement of 7.8% from 2014 to 2019. The percentage of jobs in these sectors, instead, has maintained quite constant, and is increasing again after a little drop in 2015 and 2016 years.

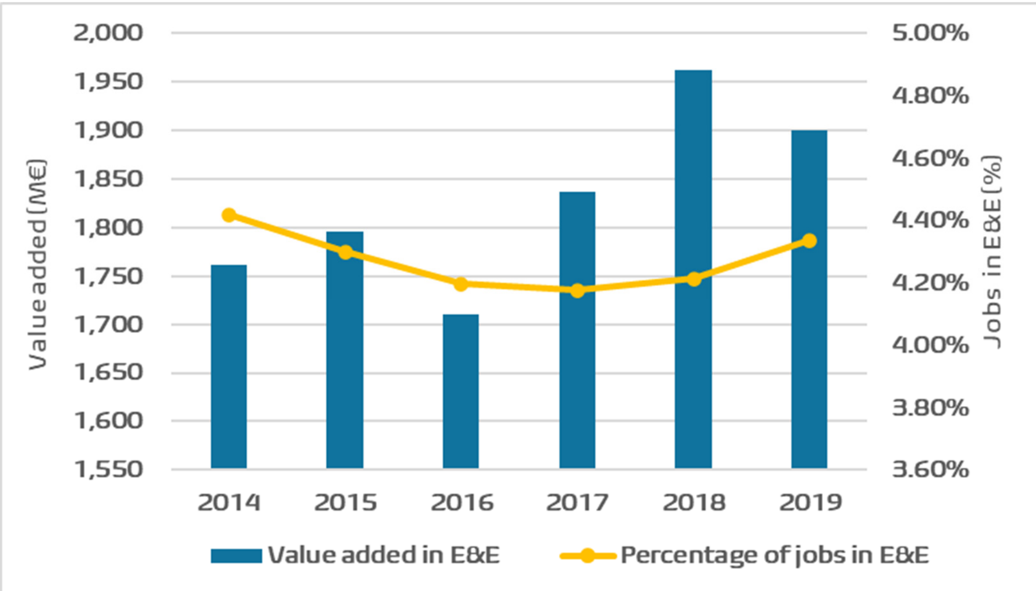

Figure 36. Value added and jobs in E&E [75]

Figure 37 shows the trends in investments in the energy sector and in public expense for environmental protection in Piemonte region, as municipal data were not available. Investments have more than doubled from 2014 to 2019, with a strong increase in the last two years, whereas public expense for environmental protection is quite stable.

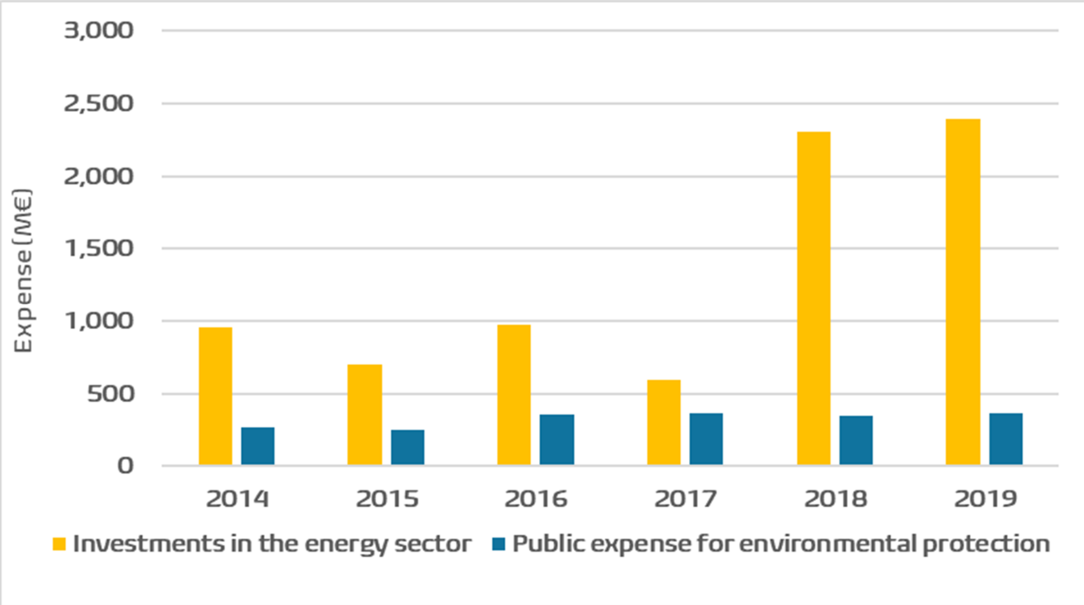

Figure 37. Investments in E&E (Piemonte) [75]

3.5 Aggregate indexes and statistical coherence

Once indicators have been calculated for each field, they have been normalized and aggregated to build field, subdomain and domain indexes.
It has to be noted that some simple indexes are not directly aggregated to build aggregate indexes at field level (e.g. *Waste*, *Water*, *GHG* indexes) but they are aggregated first with other simple indexes belonging to the same hierarchical level. This means that indexes belonging to a certain field are not necessarily simple indexes, but they could also be 1st order aggregate indexes, being obtained as aggregation of simple indexes. In particular:

- the 1st order aggregate index "Atmospheric pollutants per inhabitant in water integrated service" is calculated as the arithmetic mean of the simple indexes $AP_{water,i}$
- the 1st order aggregate index "Atmospheric pollution in waste disposal process" is calculated as the arithmetic mean of the simple indexes "PAH emissions", "Dioxins emissions" and "Number of half-hours with overrunning"
- the 1st order aggregate index "Cycle-pedestrian areas" is calculated as the arithmetic mean of the simple indexes "Pedestrian area per 100 inhabitants" and "Bike roads density"
- the 1st order aggregate index "PM_{10}" is obtained as the arithmetic mean of the simple indexes "PM_{10} yearly average concentration" and "PM_{10} yearly average concentration"
- the 1st order aggregate index "Grid quality" is obtained as the arithmetic mean of simple indexes "Average number of interruptions per LV (low voltage) user" and "Cumulative length of interruptions per LV (low voltage) user".

Table 30 reports the values of all aggregate indexes whereas in *Table 31* the results of normalization for the indicators (simple indexes) are shown. The Pearson coefficient r calculated between each index and the aggregate index of upper hierarchical level is reported as well.
It can be seen that 25 simple indexes have correlation coefficients higher than 0.4, meaning that the corresponding aggregate index in the higher level of the hierarchy (aggregate indexes at field level) well represents them. Of course, this was expected for aggregate indexes at field level having only one underlying index (e.g. *Transport*, *Tertiary*, *Residential* aggregate indexes), for which the Pearson correlation coefficient is always equal to 1. On the other hand, *Waste* aggregate index is badly correlated to 4 out of 6 underlying simple indexes, highlighting the need to consider the trends of single indicators to have a clearer view of the global performances of the field; for example, *Waste* index is not representative of "Expenditure on waste management per capita" and "Special waste generation per capita" simple indexes, whose value consistently decrease in the analysed timespan, contrary to the trend of *Waste* index. The same holds true for the *Land Use* field, for which 2 out of 4 underlying indexes show inverse correlation. Last, in the *Water* field only one simple index is weakly correlated (r=0.331) to the aggregate index of upper level, and consequently, *Water* aggregate index can still be considered a good measure of the general performances of the field.
Regarding aggregation at upper levels of the hierarchy, all field indexes, except for *Land use* field (r=-0.278) and *Energy Poverty* field (r=-0.645), are well correlated with sub-domain indexes. Sub-domain aggregate indexes have, as well, good level of correlation with their domain indexes, except in the case of *End-use sectors* sub-domain (r=-0.803). Finally, 2 out of 3 of the domain indicators are well represented by the Green Transition Index, whereas the *Energy System* domain shows no correlation with it (r=-0.078).
A possible strategy to overcome this issue is to change the weighting scheme of the proposed set of indicators, by increasing the value of weights for indicators/indexes characterized by lower correlation values, conferring larger importance to them. Still, as the value of indicators and indexes changes year by year, the same would happen for correlation's values and weights would need to be updated from time to time. Consequently, it has been decided to maintain the equal weighting scheme.
The above-mentioned considerations have highlighted the fact that aggregate indexes are not always a good measure of the performances of the underlying indexes/indicators, as they tend to level different results of the analysed phenomena which must be evaluated, case-by-case, by considering simple indicators' trajectories. Still, the proposed framework appears consistent for measuring urban performances at aggregate level for most of the analysed dimensions, and, together with results of correlation analysis, it provides a holistic view of the main urban phenomena involved in the process of green transition.

Table 30. Aggregate indexes and correlation coefficients

Index/Indicator	2014	2015	2016	2017	2018	2019	r
Green Transition Index	0.444	0.458	0.442	0.471	0.646	0.673	-
ENERGY SYSTEM	0.538	0.500	0.374	0.521	0.637	0.660	-0.078
Production	1.000	0.793	0.576	0.444	0.350	0.000	0.821
Electrical and Thermal	1.000	0.793	0.576	0.444	0.350	0.000	1.000
Networks & Storage	0.435	0.262	0.000	0.435	0.762	1.000	0.987
Power grid	0.435	0.262	0.000	0.435	0.762	1.000	1.000
End-use sectors	0.177	0.445	0.546	0.684	0.800	0.980	-0.803
Tertiary	0.000	0.607	0.707	0.841	0.817	1.000	0.937
Transport	0.000	0.000	0.191	0.469	0.782	1.000	0.933
Other	0.532	0.475	0.540	0.667	0.601	0.953	0.841
Residential	0.000	0.699	0.748	0.758	1.000	0.966	0.908
ENVIRONMENT	0.363	0.374	0.503	0.413	0.728	0.789	0.808
Resources	0.536	0.529	0.584	0.548	0.521	0.664	0.774
Water	0.402	0.372	0.540	0.535	0.605	0.931	0.948
Waste	0.451	0.480	0.619	0.514	0.420	0.631	0.711
Land use	0.526	0.552	0.466	0.448	0.444	0.479	-0.278
Emissions	0.190	0.220	0.423	0.279	0.934	0.914	0.981
GHG	0.000	0.364	0.388	0.425	0.892	1.000	0.930
Air Pollutants	0.380	0.075	0.457	0.133	0.977	0.828	0.932
SOCIO/ECONOMY	0.431	0.499	0.449	0.479	0.574	0.569	0.863
Wealth	0.431	0.499	0.449	0.479	0.574	0.569	1.000
Energy Poverty	0.472	1.000	0.704	0.640	0.263	0.000	-0.645
Jobs & VA	0.602	0.424	0.042	0.251	0.575	0.708	0.573
Investments in E&E	0.219	0.073	0.602	0.545	0.883	1.000	0.743

Table 31. Simple indexes and correlation coefficients

Index/Indicator	2014	2015	2016	2017	2018	2019	r
Electrical and Thermal							
Total energy generation from renewable energy sources	1.000	0.793	0.576	0.444	0.350	0.000	1.000
Power grid							
Grid quality	1.000	0.841	0.185	0.000	0.237	0.350	0.988
Power grid losses	0.000	0.097	0.659	1.000	0.880	0.853	0.990
Tertiary							
Energy intensity in tertiary sector	0.000	0.607	0.707	0.841	0.817	1.000	1.000
Transport							
Energy intensity in transport sector	0.000	0.000	0.191	0.469	0.782	1.000	1.000
Other							
Energy consumption per number of public spot lighting	0.140	0.000	0.603	1.000	0.861	0.859	0.670
Energy Intensity in solid waste management	0.668	0.721	0.613	0.819	0.943	1.000	0.893
Energy Intensity in wastewater management	0.955	0.938	0.874	0.827	0.789	1.000	0.230
Residential							
Energy Intensity in residential sector	0.000	0.699	0.748	0.758	1.000	0.966	1.000
Water							
Percentage of water distribution losses in aqueduct	0.929	0.143	0.107	0.143	0.000	1.000	0.331
Average daily consumption of water by inhabitant	0.000	0.071	0.357	0.357	0.500	1.000	0.995
Percentage of recycled non-hazardous waste in water integrated service	0.000	0.462	0.472	0.978	0.949	1.000	0.734
GHG emissions per equivalent inhabitant in water integrated service	0.115	0.306	0.333	0.385	0.375	1.000	0.945
Atmospheric pollutants per inhabitant in water integrated service	0.386	0.402	0.886	0.602	0.739	0.692	0.584
Waste							
Urban waste generation per capita	0.665	0.922	0.570	0.000	0.292	1.000	0.245

Index/Indicator	2014	2015	2016	2017	2018	2019	r
Recycling rate of solid waste	0.042	0.000	0.300	0.519	0.644	1.000	0.270
Expenditure on urban waste management per capita	1.000	0.595	0.707	0.703	0.218	0.179	-0.063
Gross energy generation per quantity of treated waste	0.000	0.573	0.958	1.000	0.625	0.786	0.664
Special waste generation per capita	1.000	0.179	0.368	0.198	0.004	0.000	0.075
Atmospheric pollution in waste disposal process	0.000	0.702	0.878	0.727	0.905	1.000	0.490
Land use							
Green surface per capita	0.105	0.000	0.076	0.675	0.832	1.000	-0.581
Consumed soil per capita	1.000	1.000	0.786	0.413	0.254	0.000	0.606
Urban dispersion index	1.000	1.000	0.642	0.292	0.150	0.000	0.716
Cycle-pedestrian areas	0.000	0.208	0.361	0.414	0.539	0.917	-0.429
GHG							
GHG Emissions	0.000	0.364	0.392	0.438	0.893	1.000	1.000
Air Pollution							
NO2 yearly average concentration	0.133	0.000	0.400	0.267	1.000	0.733	0.940
PM_{10}	0.626	0.149	0.515	0.000	0.955	0.923	0.949
Energy Poverty							
Energy poverty $\eta 2$	0.472	1.000	0.704	0.640	0.263	0.000	1.000
Jobs & VA							
Percentage of occupation in energy & environmental sectors	1.000	0.508	0.084	0.000	0.150	0.663	0.686
Value added energy	0.204	0.339	0.000	0.501	1.000	0.753	0.630
Investments in E&E							
Investments in the energy sector	0.203	0.060	0.213	0.000	0.953	1.000	0.844
Public expense for environmental protection	0.164	0.000	0.920	1.000	0.809	1.000	0.842

4 Conclusions

The transition of urban areas towards climate neutrality and reduced environmental impact requires the rethinking of the present cities' structure by means of suited policies able to address the multi-dimensional structure of the problem. Therefore, it is fundamental to provide science-based support to cities (through ad hoc consistent models and tools) for comparing ex ante the possible impacts of alternative policies and for assessing the effects of the implemented policies, by tracking along time the evolution of the urban system with respect to the desired goals.

The present work responded to this urgent need by proposing a built-from-scratch framework of index and indicators which, by taking into account the possible interrelations of the energy system with the environmental and socio-economic domains, is able to provide a global picture of the energy transition process to the urban policymakers.

Furthermore, the application of the developed metric system to the case study of Turin city has given the opportunity to test it, by highlighting main criticalities in the building process of index and indicators, as well as to evaluate the effectiveness of the chosen aggregation scheme.

Regarding the first aspect, one main matter of interest has been the huge sparseness of data. The case study has shown that data required for building the proposed multi-domain framework of indicators are heterogenous in nature, being contained in multiple datasets provided by different data-sources and being characterized by different formats as well. In this sense, the procedure of data mapping through formalization tables has been of importance for delivering a consistent and aggregated database at local scale for Turin city, also providing information regarding spatial and temporal granularity of the collected data. In particular, spatial granularity of the collected data mainly refers to municipal level (almost 45% of the downloaded data), followed by provincial level (27%), whereas data at "address" level, useful to conduct analyses at sub-municipal level (i.e. by city districts) only account for 3% of the downloaded data, prompting that tailored mathematical models are necessary to fill data gaps where physical data collection is infeasible. The problem of low spatial resolution for the collected data also appears evident in the case of some of the calculated indicators - such as Energy Poverty η_2 - which are referred to regional level instead than municipal level. Because of this, cities should consider the possibility of collecting data (for example, through annual questionnaires) on their own to better estimate and respond to some of the phenomena involved in the energy transition process at urban scale.

On the other hand, temporal granularity of the collected data has proven to be consistent for the scopes of this work, as downloaded data are mainly referred to the annual scale (67% of the total downloaded data); however, the related datasets are sometimes characterized by larger time granularity (e.g. a dataset published each five years containing data with annual time granularity), making difficult the continuous updating of some indexes and indicators. To overcome this issue, it is advisable for local authorities to develop agreements with data providers, obtaining data with the desired time granularity prior of their effective publication.

Developing - where possible - agreements with data providers is also fundamental to ensure that data are always provided with the same format; this, indeed, is required to automatize the process of indicators' calculation as well as to avoid pre-elaboration of raw data.
These aspects, together with the choice of elaborating indicators basing on data sources which have consistently updated their publications in the analysed timespan, opens the path for the future construction of index and indicators' time series that, for this work, have been focused on 2014-2019 period only, as many necessary data were not available out of this time range.
Building longer and longer time series, in fact, proves essential for deriving meaningful insights on the analysed phenomena, reducing the chance that possible outliers in data distort the delivered results.
This is particularly important for the sake of normalization as well which, for the case study, has been evaluated in the temporal dimension (i.e. across years) through min-max method. Indeed, rescaling in time an indicator characterized by low variance could lead to distorted results, since the variance of the related simple index (i.e. the normalized indicator) would not be the same. Consequently, as the value of indicators is expected to change more (and then, to have larger variance) in longer timespans, extending time series results of primary importance for delivering consistent time-normalized indicators.
Another future perspective of the developed metric system regards the choice of normalization criterion. In this work, as the goal was to measure performances of a unique city, indicators have been rescaled in time, by considering best and worst performances for all the indicators in the timespan of analysis within the city itself. However, to promote competition among municipal authorities and ensure that best available techniques are more easily diffused among cities, the rescaling of indicators with respect to best and worst performances across various municipalities could also be carried out. In this sense, it has to be noted that almost 41% of the downloaded data needed for building both core and supporting indicators are retrieved from national institutes and are then already available for other Italian chief cities of province, whereas, for the other data, it should be verified if municipal and regional datasets exist.
In relation to the completeness of the produced set of indexes and the effectiveness of the chosen aggregation scheme, some remarks should also be made.
First, the idea which drove the entire process of development of the urban metric system has been that of delivering a set of index and indicators useful for tracking phenomena whose dynamics could be managed and/or influenced by local authorities.
The conceptual scheme of the developed metric system has then been based on the distinction among energy system, environment and socio-economic domains; each of them is further declined in the related sub-domains and fields, for which multiple indicators are identified.
The *Energy system* domain, through the sub-domains of *Production*, *Networks & Storage* and *End-use sectors*, aims at evaluating the energy supply chain at local level, by focusing on the aspects of renewable energy generation, energy infrastructures, energy intensity and structure of end-use sectors and, where data are available, also trying to capture the drivers of change in energy consumption. It has to be noted that indicators for *Industry* end-use sector

(subdomain *End-use sectors)*, *District Heating* and *Natural Gas* distribution networks and *Storage systems* (subdomain *Networks & Storage*) have not been evaluated since data were insufficient for the analysed case study.

The *Environment* domain has the purpose of evaluating the use and management of resources available at local level (*Resources* sub-domain), which comprise water, waste and soil, as well as the gaseous emissions (*Emissions* sub-domain) produced in the municipality, which regards main air pollutants and GHG emissions, being the two themes strictly related to the process of energy transition at urban level. In particular, the management of water and waste resources has been evaluated by recreating the related cycles and building indicators for each phase (in relation to data availability), whereas the analysis of the soil resource (*Land use* field) has been based on the density of built-up areas, green spaces and cycle-pedestrian areas. On the other hand, the evaluation of air pollutant emissions focuses on NO_X and PM_{10}, whereas CO_2 is the only GHG considered in the analysis, as data for other GHGs were not available for the case study. It should be noted that, in the Environment domain, the *Climate* sub-domain has also been considered in the initial stage of database design even if no related indicators have been developed next. The reason for this is that drivers for climate change have global scale and cannot be addressed by local authorities only. Still, climate change impacts at urban level (i.e. urban heat islands) need to be monitored and modelled, as they can represent a threat for citizens' wellbeing in the next years.

The *Socio-economy* domain is used instead for analysing the possible advantages, created by energy transition, and impacts, caused by energy consumption and local pollution, on citizens, as well as the dynamism of the local eco-energetic economical activities. This is done through the tracking of eco-energy jobs, energy poverty, energy-related investments and value added by local activities. However, for the proposed target of measuring health impacts provoked by local air pollution, no valuable figure of merit – interrelating the two phenomena year-by-year – has been found in the case of Turin city.

Then, to synthetize the multi-dimensionality of the process in a compact manner, aggregate indexes have also been evaluated. Starting from a subset of indicators, an aggregate index for each field, sub-domain and domain of the conceptual framework – plus a global index (i.e. the Green Transition Index) obtained as aggregation of the three domains' indexes – has been built.

The aggregation process has been carried out through a compensatory approach; this means that underperformance of one indicator can be compensated by overperformance of another one. In this sense, to have a clearer view of the analysed phenomena, for each aggregate index it is recommended to consider the underlying indicators. Furthermore, in the perspective of extending the evaluation of indicators to other cities, the aggregation method could also be modified with a non-compensatory method which penalises underperformances in single indicators, incentivizing cities to improve their performances where low-scores indexes are present.

Even if aggregate indexes are useful for compacting information of the underlying indicators, their main drawback is related to the presence of trade-off among indicators' scores. This phenomenon should be avoided as much as possible, since the aggregate index would result to be unrepresentative of some of the underlying indicators. Literature review has shown that, when building aggregate indexes, a useful parameter to evaluate the degree of relation of an indicator/index with the related upper-level aggregate index is the Pearson correlation coefficient. Ideally, in order to create aggregate indexes containing a balanced contribution of information from all the underlying indicators/indexes, the values of Pearson correlation coefficient between indicators/indexes and upper-level aggregate index should be similar. However, the results obtained for the case study of Turin show that this is not always the case. In particular, the Green Transition Index turns out to be badly correlated with the Energy System domain, and it is then advised to consider individual trajectories of the lower-level indexes, rather than their aggregated values. The concept holds true also for other aggregate indicators/indexes showing low correlation values with the related aggregate index. Integrating the metric system with indicators based on missing data highlighted above, the developed set of indicators proves then to be consistent in measuring the main cross-sectoral phenomena involved in the context of local energy transition and, by means of aggregate indexes complemented with correlation coefficients, the multi-dimensional nature of the process can also be evaluated in a compact manner.

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Appendix

1. Formalization attributes

CATEGORY	NAME	SYMBOL
Domain	Energy System	ES
	Environment	En
	Socio/Economy	S/EC
Subdomain	Production	P
	Networks&Storage	N&S
	End-use sectors	EUs
	Resources	Re
	Emissions	E
	Climate	Cl
	Wealth	We
	Health	H
Field	Electricity	El
	Heat	Th
	Power grid	Pg
	District heating	DH
	Storage	St
	Residential	Re
	Tertiary	Te
	Transport	Tr
	Industry	In
	Other	O
	Land Use	LU
	Waste	W
	Water	Wat
	Greenhouse gases	GHG
	Air Pollutants	AP
	Temperature	T
	Energy Poverty	EP
	Jobs and Value added	J&VA
	Investments	Inv

CATEGORY	NAME	SYMBOL
Data category	Basic figure	b
	Indicator	i
	Simple Index	I0
	Aggregate index of n level	In

2. Formalization tables – Datasets, downloaded data and elaborated data

			Access		For free	Domain				Format	Time granularity									Spatial granularity						Time extent		Download		
ID	Name	Data source	O	C	Y	En	ES	S/EC	Link	E/P/M/W/Z	Gh	Gd	Gw	Gf	Gm	Gq	Gs	Gy	S	A	PS	PC	C	P	R	From	To	Auto	Manual	Note
DT1	Dati di produzione e raccolta differenziata	ISPRA	X		X	X			https://www.catasto-rifiuti.isprambiente.it/index.php?pg=downloadComune	E								X					X			2010	2020	X		dati fino al dettaglio provinciale: 2001-2020
DT2	Dati sui costi di gestione dei rifiuti urbani (pro capite o per chilogrammo di rifiuto)	ISPRA	X		X	X			https://www.catasto-rifiuti.isprambiente.it/index.php?pg=downloadcosticomune	E								X					X			2011	2019	X		
DT3	Rifiuti_Produzione rifiuti speciali	ARPA PIEMONTE	X		X	X			http://webgis.arpa.piemonte.it/secure_apps/rifiuti_spec_webapp/	M								X					X			2011	2019	X		
DT4	Aria - la qualità dell'aria in Piemonte (Misure)	ARPA PIEMONTE	X		X	X			https://aria.ambiente.piemonte.it/#/qualita-aria/dati	E/W	X										X					2000	2022	X		Il dataset rende disponibili i dati solo secondo una particolare stazione di rilevamento emissioni
DT5	Bilancio di sostenibilità SMAT	SMAT	X			X			https://www.smatorino.it/bilanci-economici-e-di-sostenibilita/	P								X			X					2007	2021	X		
DT6	Ambiente urbano - Verde Urbano	ISTAT	X		X	X			https://www.istat.it/it/files//2021/12/Tavole-1.zip	E								X						X	X	2000	2020	X		Unzip -> VERDE_URBANO_2020 (TAV.12.2)
DT7	Consumo del suolo	ISPRA	X		X	X			https://groupware.sinanet.isprambiente.it/uso-copertura-e-consumo-di-suolo/library/consumo-di-	E								X					X			2006	2020	X		I dati sono disponibili con granularità annua dal 2015 al 2020; sono anche presenti i dati per gli
DT8	Istat_Tavole_Censimento_acque_per_uso_civile	ISTAT	X		X	X			https://www.istat.it/it/files//2020/12/Istat_Tavole_Censimento_acque_per_uso_civile_2018-3.xlsx	E									X					X		1999	2018			Dati disponibili per gli anni 1999 2005 2008 2012 2018, dal 2018 dati raccolti con cadenza biennale
DT9	Catasto Impianti Termici	REGIONE PIEMONTE		X	X		X		https://servizi.regione.piemonte.it/catalogo/catasto-impianti-termici	E																				
DT10	Iren - Bilancio di sostenibilità	IREN	X		X		X		https://www.gruppoiren.it/it/sostenibilita/bilanci-di-sostenibilita-dnf.html	P								X					X			2016	2021	X		en. Elettrica totale distribuita, volumetrie e abitanti serviti teleriscaldamento, dati su
DT11	Ambiente urbano - Energia	ISTAT	X		X		X		https://www.istat.it/it/archivio/ambiente+urbano	E								X						X		2000	2020	X		La rilevazione Ambiente Urbano è effettuata da ISTAT dall'anno 2000, il tipo di dati potrebbe
DT12	Dichiarazione non finanziaria	GTT	X		X		X		https://gtt.to.it/cms/risorse/fornitori/trasparenza/pdf/DatiUlteriori/DNF_2020.pdf	P									X				X			2019	2020	X		Dati simili sono presenti su Rapporto urbano ISTAT categoria mobilità (hanno il vantaggio di
DT13	Autoritratto_2021 - Circolante_Copert_2021	ACI	X		X		X		https://www.aci.it/fileadmin/documenti/studi_e_ricerche/dati_statistiche/autoritratto2021/Consistenza_parco_veicoli_2021.rar	E									X				X			2002	-	X		
DT14	Open Parco Veicoli	ACI	X		X		X		https://opv.aci.it/WEBDMCircolante/	E								X					X			2015	2021	X		Il tipo di dati potrebbe variare per i dataset più vecchi
DT15	Ambiente urbano - Mobilità	ISTAT	X		X		X		https://www.istat.it/it/files//2022/07/tavole_allegate.zip	E								X						X		2000	2020	X		La rilevazione Ambiente Urbano è effettuata da ISTAT dall'anno 2000, il tipo di dati potrebbe
DT16	Ambiente urbano - Eco management (dati su illuminazione pubblica)	ISTAT	X		X		X		https://www.istat.it/it/files//2022/07/tavole_allegate.zip	E								X						X		2000	2020	X		
DT17	Consumi energetici, Impianti e Attestazione di Prestazione Energetica - APE	REGIONE PIEMONTE		X	X		X		https://servizi.regione.piemonte.it/catalogo/iocomune-valorizzazione-dati-degli-enti-locali	-													X							Il dato su totale consumo energia elettrica è presente anche sul rapporto urbano istat
DT18	Popolazione residente ricostruita - Anni 2002-2019	ISTAT	X		X			X	http://dati.istat.it/Index.aspx?DataSetCode=DCIS_RICPOPRES2011#									X					X			2002	2019	X		Il dato sulla popolazione totale può essere esteso al periodo 2019-2022 mediante un altro
DT19	Reddito e principali variabili IRPEF su base subcomunale/comunale	MINISTERO DELL'ECONOMIA E FINANZE	X		X			X	https://www1.finanze.gov.it/finanze/analisi_stat/public/v_4_0_0/contenuti/Redditi_e_principali_variabili_IRPEF_su_base_subcomunale_CSV_2020.zi	E								X				X	X			2012	2020	X		
DT20	Mortalità per cause	REGIONE PIEMONTE	X		X			X	http://www.ruparpiemonte.it/infostat/filtri.jsp?cambia_FILTRO15=-1	E								X					X			1980	2019	X		
DT21	Mortalità per territorio di evento	ISTAT	X		X			X	http://dati.istat.it/Index.aspx?DataSetCode=DCIS_CMORTE1_EV	E								X								2003	2019	X		
DT22	AAEP - Anagrafe delle Attività Economiche Produttive - Consultazione	REGIONE PIEMONTE		X				X	https://servizi.regione.piemonte.it/catalogo/aaep-anagrafe-delle-attivita-economiche-produttive-consultazione	E																				Dataset utile per tracciare l'evoluzione del numero di industrie nel settore energetico
DT23	Principali aggregati territoriali di Contabilità Nazionale - Valore aggiunto per branca di attività	ISTAT	X					X	http://dati.istat.it/Index.aspx?DataSetCode=DCCN_TNA_B14	E								X					X			2005	2019	X		
DT24	Imprese e addetti	ISTAT	X		X			X	http://dati.istat.it/Index.aspx?DataSetCode=DICA_ASIAUE1P	E								X					X			2012	2020	X		
DT25	Principali aggregati territoriali di Contabilità Nazionale - Investimenti fissi,lordi,interni e Spesa per consumi finali delle amministrazioni pubbliche	ISTAT	X					X	http://dati.istat.it/Index.aspx?DataSetCode=DCCN_TNA_B14	E								X								2005	2021	X		
DT26	TAPE	COMUNE DI TORINO	X		X	X	X		http://www.comune.torino.it/ambiente/cambiamenti_climatici/patto_dei_sindaci/il-piano-dazione-2.shtml	P									X				X			2010	2022	X		
DT27	Torino - Informacasa	COMUNE DI TORINO	X		X		X		http://www.comune.torino.it/informacasa/	P									X				X			2009	2020	X		
DT28	Analisi del potenziale solare per i comuni dell'area metropolitana torinese	PROVINCIA DI TORINO	X		X		X		http://www.cittametropolitana.torino.it/cms/risorse/ambiente/dwd/ris-energetiche/osservatorio_energia/portale_solare/mappe_solari/scheda_b	P									X				X			-	-	X		
DT29	Relazione annuale relativa al funzionamento e alla sorveglianza dell'impianto - Termovalorizzatore Gerbido	IREN	X		X	X	X		https://trm.to.it/trasparenza/	P								X			X					2017	2022	X		see informazioni ambientali -> relazione annuale
DT30	Dichiarazione ambientale - Centrale di cogenerazione Torino Nord	IREN	X		X		X		https://www.gruppoiren.it/it/i-nostri-servizi/produzione-energia/impianti-di-cogenerazione.html	P								X			X					2014	2021	X		
DT31	Dichiarazione ambientale - Centrale di cogenerazione Moncalieri	IREN	X		X		X		https://www.gruppoiren.it/it/i-nostri-servizi/produzione-energia/impianti-di-cogenerazione.html	P								X			X					2006	2022	X		
DT32	STATO D'AVANZAMENTO ATTIVITA' DISCARICA E ATTIVITÀ DI GESTIONE DEL BIOGAS	AMIAT	X		X		X		https://www.amiat.it/documents/597091/624022/Impianto+interramento+controllato_Relaz+tecnica+2021.pdf/a92128ee-774d-4835-831b-	P									X				X			2020	2020			
DT33	Annuario Statistico - Settore toponomastica ed edilizia	COMUNE DI TORINO	X		X		X		http://www.comune.torino.it/statistica/osservatorio/annuario/2020/	P								X					X			2001	2021			
DT34	INDAGINE SULLE SPESE DELLE FAMIGLIE: MICRODATI AD USO PUBBLICO	ISTAT	X					X	https://www.istat.it/it/archivio/180356	Z								X							X	2014	2021			
DT35	Clima_Gradi giorno di riscaldamento	ARPA PIEMONTE	X		X	X			https://www.arpa.piemonte.it/rischinaturali/accesso-ai-dati/selezione-gradi-giorno/selezione-gradi-giorno.html	E								X			X					2005	2021			

ID	Symbol	Name	ID dataset	link	General information																				u.m.	Specific information																NOTE
					Category		EN						ES								S/EC					Format	Time granularity										Spatial granularity					
							Cl	E			Re		P		N&S			TU			H	We				E/P/M/W/Z	Gh	Gd	Gf	Gw	Gm	Gq	Gs	Gy	S	Ad	PS	CAP	C	P	R	
					d	b	T	GHG	AP	LU	Wat	W	El	H	Pg	O	Re	Ind	Ter	Tra		EP	J&VA	Inv																		
dd1	W_U	Urban_waste_generation_per_capita	DT1	https://www.catasto-rifiuti.isp		X						X													kg/ab.*anno	E								X					X			
dd2	W_U,rec	Recycling_rate_of_solid_waste	DT1	https://www.catasto-rifiuti.isp		X						X													%	E								X					X			
dd3	WC_U	Expenditure_on_urban_waste_management_per_capita	DT2	https://www.catasto-rifiuti.isp		X						X													€/(ab.*anno)	E								X					X			
dd4	W_wi	Amount_of_waste_treated_at_Gerbido_incineration_plant	DT29	https://www.irenambiente.it/termo	X							X													t	P								X			X					
dd5	Ewi_j	Energy_consumption_for_waste_incineration_by_carrier_j	DT29	https://trm.to.it/trasparenza/	X							X													MWh (electricity) Sm3 (Gas)	P								X			X					
dd6	APlim_wi_k	Number_of_exceedances_of_half_hours_limit_values_for_air_pollutant_emitted_by_Gerbido_waste_incineration_plant_line_k	DT29	https://trm.to.it/trasparenza/	X							X													-	P								X			X					
dd7	AP_wi^j_k	Concentration_of_air_pollutant_j_emitted_by_Gerbido_waste_incineration_plant_line_k	DT29	https://trm.to.it/trasparenza/	X							X													pg/Nm^3 or ng/Nm^3	P								X			X					
dd8	W_S,nh	Special_non-hazardous_waste	DT3	http://webgis.arpa.piemonte.it/sec	X							X													t	M								X					X			
dd9	W_S,nh	Special_hazardous_waste	DT3	http://webgis.arpa.piemonte.it/sec	X							X													t	M								X					X			
dd10	Wa_sup,qual	Compliance_with_quality_standards_for_water_supply	DT5	https://www.smatorino.it/bilanci-		X					X														%	P								X			X					
dd11	Wa_sup,par	Number_of_verified_parameters_for_water_quality_supply_per_inhabitant	DT5	https://www.smatorino.it/bilanci-		X					X														-	P								X			X					
dd12	Wa_tr,pop	Percentage_of_population_served_by_wastewater_treatment_plants	DT5	https://www.smatorino.it/bilanci-		X					X														-	P								X			X					
dd13	Wa_distr,loss	Percentage_of_water_losses_in_aqueduct	DT5	https://www.smatorino.it/bilanci-		X					X														-	P								X					X			
dd14	E_wat,cons	Total_energy_consumption_for_water_integrated_service	DT5	https://www.smatorino.it/bilanci-		X					X														MWh	P								X					X			
dd15	Pop_wa,eq	Equivalent_population_served_by_integrated_water_service	DT5	https://www.smatorino.it/bilanci-		X					X														-	P								X					X			
dd16	W̄	Amount_of_consumed_water_per_inhabitant_day	DT8	https://www.istat.it/it/files//2020/1		X					X														l/(ab*day)	E									X				X			
dd17	Wa_NHW,rec	Amount_of_recycled_non_hazardous_waste_from_wastewater_treatment_plants	DT5	https://www.smatorino.it/bilanci-	X						X														kg	P									X				X			
dd18	Wa_NHW	Amount_of_non_hazardous_waste_from_wastewater_treatment_plants	DT5	https://www.smatorino.it/bilanci-	X						X														kg	P									X				X			
dd19	GHG_wa,i	GHG_emissions_from_source_i_in_water_integrated_service	DT5	https://www.smatorino.it/bilanci-	X						X														ton	P									X				X			
dd20	m_pol,wa_i	Mass_of_ith_pollutant_produced_in_integrated_water_system	DT5	https://www.smatorino.it/bilanci-	X						X														ton or kg	P									X				X			Pollutants: CO, NMVOC, polveri sottili, NOX, SOX, NH3
dd21	η_wa,tr_i	Efficiency_in_water_pollution_removal_in_Castiglione_wastewater_treatment_plant	DT5	https://www.smatorino.it/bilanci-	X						X														%	P									X				X			Pollutants: SST,BOD,COD,P,N
dd22	GS	Urban_green_surface	DT6	https://www.istat.it/it/files//2021/1	X					X															m^2	E								X					X	X		
dd23	CS	Consumed_soil	DT7	https://groupware.sinanet.isprambi	X					X															ha	E									X				X			
dd24	UDI	Urban_Dispersion_index	DT7	https://groupware.sinanet.isprambi		X				X															-	E								X					X			Ratio between low and low+high urban density areas
dd25	AP_NOx,i^ya	NOx_yearly_average_measurement_station_i	DT4	https://aria.ambiente.piemonte.it/#		X			X																microg/m^3	W								X			X					Stations: Lingotto,Rubino (only background stations)
dd26	AP_PM10,i^ya	PM10_yearly_average_measurement_station_i	DT4	https://aria.ambiente.piemonte.it/#		X			X																microg/m^3	W								X			X					Stations: Lingotto,Rubino (only background stations)

dd27	AP_PM10,i^hae	PM10_hourly_average_exceedances_measurement_station_i	DT4	https://aria.ambiente.piem		X			X																microg/m^3	W								X			X					Stations: Lingotto,Rubino (only background stations)
dd28	REP^E_1,Moncalieri	Net_renewable_electricity_production_hydro	DT31	https://www.grupporen.it	X								X												GWh	P								X			X					
dd29	REP^E_3	Net_renewable_electricity_production_solar	DT11	https://www.istat.it/it/arch	X								X												kWh	E									X				X			
dd30	REP^E_5b,Stura	Net_renewable_electricity_production_biogas	DT32	https://www.amiat.it/docu	X								X												kWh	P											X					
dd31	REP^T_2	Net_renewable_thermal_production_solar_heaters	DT26	http://www.comune.torin		X								X											MWh	P								X					X			
dd32	REP^T_4	Net_renewable_thermal_production_solid_biomass	DT26	http://www.comune.torin		X								X											MWh	P								X					X			
dd33	C_PV,in	Capacity_PV_per_inhabitant	DT11	https://www.istat.it/it/arch		X							X												kW/1000 ab	E								X					X			
dd34	D1	Cumulative_duration_of_disconnection_from_power_grid	DT10	https://www.grupporen.it		X									X										min	P								X					X			
dd35	N1	Average_number_of_disconnection_by_LV_user	DT10	https://www.grupporen.it		X									X										-	P								X					X			
dd36	PGL	Power_grid_losses	DT10	https://www.grupporen.it		X									X										%	P								X					X			
dd37	EV_tot	Total number of EV charging points	DT11	https://www.istat.it/it/files	X										X										-	E								X						X		
dd38	EV_res	Percentage of EV charging points supplied by renewable energy sources	DT11	https://www.istat.it/it/files		X									X										%	E								X						X		
dd39	PT_bus,j	Urban_bus_by_emission_class_EURO_j	DT12	https://gtt.to.it/cms/risors	X				X											X					-	P								X					X			
dd40	PT_em,j	Public_transport_emissions_by_category_j	DT12	https://gtt.to.it/cms/risors	X			X	X											X					t	P								X					X			Data available for the years 2015,2018,2019,2020. Total urban emission by category j. [illegible]
dd41	BRD	Bike_roads_density	DT15	https://www.istat.it/it/files		X				X										X					km/km^2	E								X						X		Data is reported for provinces but it is referred to the municipal area
dd42	PA_POP	Pedestrian_area_per_100_inhabitants	DT15	https://www.istat.it/it/files		X				X										X					10^3 m^2	E								X						X		
dd43	Car_j	Cars_by_fuel_j	DT14	https://opv.aci.it/WEBDMC	X															X					-	E								X					X			
dd44	PL_led	Public_light_points_LED	DT16	https://www.istat.it/it/files	X											X									-	E								X						X		Number of LED light points
dd45	PL_tot	Public_light_points_total	DT16	https://www.istat.it/it/files	X											X									-	E								X						X		
dd46	PL_regfl	Public_light_points_regulated_flux	DT16	https://www.istat.it/it/files	X											X									-	E								X						X		Number of light points equipped with a regulator of luminous flux
dd47	Pop	Population	DT18	http://dati.istat.it/Index.as	X																			X	-	E								X					X			
dd48	TI_j	Total_income_by_IRPEF_class,j	DT19	https://www1.finanze.gov.i	X																			X	€	E								X				X				
dd49	TP_j	Taxpayers_by_IRPEF_class,j	DT19	https://www1.finanze.gov.i	X																			X	-	E								X				X				
dd50	Empl_j	Number_of_employees_by_ATECO_class_j	DT24	http://dati.istat.it/Index.as	X																			X	-	E								X					X			ATECO classes: sectors D and E
dd51	VA_j	Value_added_by_ATECO_class_j	DT23	http://dati.istat.it/Index.as	X																			X	€	E								X					X			ATECO classes: sectors D and E
dd52	Inv_j	Investments_by_ATECO_class_j	DT25	http://dati.istat.it/Index.as	X																			X	€	E								X							X	ATECO classes: sectors D and E
dd53	Inv_pa,j	Spending_by_coicop_class_j	DT25	http://dati.istat.it/Index.as	X																			X	€	E								X							X	ATECO classes: sectors D and E

dd54	DD	Heat_degree_days	DT35	https://www.arpa.piemonte.it/repo		X	X																		°C	E								X			X					
dd55	D_j	Deaths_by_cause_j	DT47,DT48	http://www.ruparpiemonte.it/infor	X																X				-	E								X					X			
dd56	Eh_j	Final_consumption_household_by_carrier_j	DT26	http://www.comune.torino.it/ambi		X											X								MWh	P									X				X			
dd57	Em_j	Final_consumption_municipal_by_carrier_j	DT26	http://www.comune.torino.it/ambi		X											X								MWh	P									X				X			
dd58	E_pl	Final_consumption_public_lighting	DT26	http://www.comune.torino.it/ambi		X										X									MWh	P									X				X			
dd59	Et_j	Final_consumption_tertiary_by_carrier_j	DT26	http://www.comune.torino.it/ambi		X													X						MWh	P									X				X			
dd60	Ein_j,k	Final_consumption_industry_of_carrier_j_by_ATECO_k	DT26	http://www.comune.torino.it/ambi		X												X							MWh	P									X				X			
dd61	Etr_j	Final_consumption_transport_by_carrier_j	DT26	http://www.comune.torino.it/ambi		X														X					MWh	P									X				X			
dd62	Etr_pub,j	Final_consumption_public_transport_by_category_j	DT12	https://gtt.to.it/cms/risorse/fornito	X															X					tep	P								X					X			Categories: electric buses, methane buses, diesel buses, tram, metro. Data are provided in TEP, needed
dd63	Etr_car,j	Final_consumption_car_by_carrier_j	DT26	http://www.comune.torino.it/ambi		X														X					MWh	P									X				X			
dd64	H_tot	Household_number	DT27	http://www.comune.torino.it/infor	X												X								-	P								X					X			
dd65	Cmax_PV	Available_capacity_for_PV_installations_on_household's_roof	DT58	http://www.cittametropolitana.tori		X							X												MW	P									X				X			
dd66	Ep_M,k	Moncalieri_CHP_energy_production_k	DT30	https://www.gruppoiren.it/it/i	X								X	X											GWh	P								X			X					
dd67	η_M,k	Moncalieri_CHP_efficiency_k	DT30	https://www.gruppoiren.it/it/i		X							X	X											-	P								X			X					
dd68	Ep_TN,k	Torino_nord_CHP_energy_production_k	DT31	https://www.gruppoiren.it/it/i	X								X	X											GWh	P								X			X					
dd69	η_TN,k	Torino_nord_CHP_efficiency_k	DT31	https://www.gruppoiren.it/it/i		X							X	X											-	P								X			X					
dd70	Ep_wi^k	Gerbido_waste_incinerator_k_energy_production	DT29	https://trm.to.it/trasparenza/	X							X	X												GWh	P								X			X					
dd71	η_wi	Gerbido_waste_incinerator_efficiency	DT29	https://www.irenambiente.it/termo	X									X											-	P									X		X					
dd72	RA	Residential_area	DT33	http://www.comune.torino.it/stati	X					X							X								m^2	P								X					X			
dd73	B5_bf	Family_spending_for_electrical_energy	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd74	B10_bf	Family_spending_for_natural_gas	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd75	B27_bf	Family_spending_for_central_heating	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd76	B30_bf	Family_spending_for_district_heating	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd77	B59_bf	Family_spending_for_other_gas	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd78	B63_bf	Family_spending_for_crude_oil	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd79	B67_bf	Family_spending_for_coal	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd80	B71_bf	Family_spending_for_solid_biomass	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	

dd81	n_comp_i	Number of i-th family components	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd82	s_i	Family_i_spending_global	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd83	w_i	Family_weight	DT34	https://www.istat.it/it/archivio/1803	X																			X	€	Z								X							X	
dd84	D_tr,car	Total_distance_travelled_by_car	DT26	http://www.comune.torino.it/ambi	X															X					km	P								X					X			
dd85	Pd_tr,urbp	Total_passenger_distance_travelled_by_urban_public_transport	DT12	https://gtt.to.it/cms/risorse/fornite	X															X					€	P								X							X	Urban public transport includes buses, metro and tram
dd86	Pd_tr,me	Total_passenger_distance_travelled_by_metro	DT12	https://gtt.to.it/cms/risorse/fornite	X															X					€	P								X							X	
dd87	Se_tr,i	Total_number_of_seats_public_transport_by_category_j	DT12	https://gtt.to.it/cms/risorse/fornite	X															X					€	P								X							X	
dd88	D_tr,urbp_i	Total_distance_travelled_by_public_transport_category_i	DT12	https://gtt.to.it/cms/risorse/fornite	X															X					€	P								X							X	
dd89	Car_E,j	Cars_by_emitting_class_EURO_j	DT13	https://www.aci.it/fileadmin/docum	X				X											X					-	E								X					X			
dd90	GHG_j	GHG_emissions_by_energy_sector	DT26	http://www.comune.torino.it/ambi	X			X												X					t	P								X					X			
dd90	GHG_j	GHG_emissions_by_energy_sector	DT26	http://www.comune.torino.it/ambi	X			X												X					t	P								X					X			

ID	General information				Specific information																			
	Symbol	Name	Category		ALPHANUMERICAL CODE	Description	FORMULA	u.m.	Time granularity										Spatial granularity					NOTE
			i	I					Gh	Gd	Gf	Gw	Gm	Gq	Gs	Gy	S	Ad	PS	CAP	C	P	R	
ee1	WEG	Gross energy generation per amount of treated waste	X		En-Re-W*WEG*i	Calculated as the sum of electric and thermal energy production from waste incineration divided by the amount of incinerated waste	WEG=(〖EP〗_wi^E+EP_wi^T)/W_wi	MWh/ton								X			X					
ee2	IWEG	Normalized gross energy generation per amount of treated waste		X	En-Re-W*IWEG*I0		MIN-MAX NORMALIZATION	-								X			X					
ee3	EIw	Energy consumption per amount of treated waste	X		En-Re-W*Eiwé*i	Calculated as the ratio between the total energy consumption during waste treatment and the amount of treated waste	EIw=(Ewi_el+Ewi_gas·LHV_GAS)/V	MWh/ton								X			X					The indicator is evaluated on the basis of
ee4	IEIw	Normalized energy consumption per amount of treated waste		X	En-Re-W*IEIw*I0		MIN-MAX NORMALIZATION	-								X			X					
ee5	W_S	Special waste production per capita	X		En-Re-W*W_S*i	Calculated as the ratio between the total amount of special (hazardous and non-hazardous) waste generated and the number	W_S=〖(W〗_(S,H)+W_(S,NH))·1000	kg/ab*anno								X					X			
ee6	IW_S	Normalized special waste production per capita		X	En-Re-W*IW_S*I0		MIN-MAX NORMALIZATION	-								X					X			
ee7	APlim_(wi,tot)	Number of exceedances of limits for atmospheric pollution in waste incineration process	X		En-Re-W*APlim_(wi,tot)*i	Total number of exceedances of half-hours limit values for pollutants indicated in the notes, where k represents the number of the	APlim_(wi,tot)=∑_(k=1)^n▒〖APli〖	-								X			X					HCl,CO,NOx,SO2,COT,fine dust, HF,NH3
ee8	AP_wi^j	Average concentration of pollutants emitted in waste incineration process	X		En-Re-W*AP_wi^j*i	Average concentration of pollutant j (IPA or dio:	AP_wi^j=∑_(k=1)^n▒(AP_(wi,k)^j)	pg/Nm^3 (dioxin) ng/Nm^3								X			X					Pollutants: IPA, dioxin
ee9	IAP_wi^j	Normalized number of exceedances of limits for atmospheric pollution in waste incineration process		X	En-Re-W*IAP_wi^j*I0	-	MIN-MAX NORMALIZATION	-								X			X					
ee10	IAPlim_(wi,tot)	Normalized average concentration of pollutants emitted in waste incineration process		X	En-Re-W*IAPlim_(wi,tot)*I0	-	MIN-MAX NORMALIZATION	-								X			X					
ee11	API_wi	Atmospheric pollution impact of waste incineration process		X	En-Re-W*API_wi*I1	First order aggregate index measuring the impact of waste incineration on atmospheric pollution	API_wi=(∑_(j=1)^n▒〖IAP_wi^j 〗+I/	-								X			X					
ee12	IW	Waste index		X	En-Re-W*IW*I2	Second order aggregate index measuring waste management performances	IW=(IWEG+IW_S+API_wi+IW_U+IW	-																
ee13	GS_cap	Green surface per capita	X		En-Re-LU*GS_cap*I0	Amount of green surface per inhabitant (excluding urban forests)	GS_cap=GS/Pop·10	ha/100.000 inhab								X					X			
ee14	IGS_cap	Normalized green surface per capita		X	En-Re-LU*IGS_cap*i		MIN-MAX NORMALIZATION	-								X					X			
ee15	CS_cap	Consumed soil per capita	X		En-Re-LU*CS_cap*i	Amount of consumed soil per capita	CS_cap=CS/Pop·100 000	ha/100.000 inhab								X					X			defined as the amount of soil characterized by
ee16	ICS_cap	Normalized consumed soil per capita		X	En-Re-LU*ICS_cap*I0		MIN-MAX NORMALIZATION									X					X			
ee17	IUDI	Normalized urban dispersion index		X	En-Re-LU*IUDI*I0		MIN-MAX NORMALIZATION									X					X			
ee18	CPI	Cycle-pedestrian area index		X	En-Re-LU*CPI*I1	First order aggregate index measuring the extension of bike roads and pedestrian areas in the municipality	CPI=(IBRD+IPA)/2	-								X					X			
ee19	IBRD	Normalized bike road density		X	En-Re-LU*IBRD*I0	-	MIN-MAX NORMALIZATION	-								X					X			

ee20	IPA	Normalized pedestrian area		X	En-Re-LU*IPA*I0	-	MIN-MAX NORMALIZATION	-								X					X		
ee21	ILU	Land use index		X	En-Re-LU*ILU*I2	Second order aggregate index measuring land use changes	ILU=(CPI+IGS_cap+ICS_cap+IUDI)/4	-								X					X		
ee22	API_PM10^ya	PM10 yearly average	X		En-Re-AP*API_PM10^ya*i	Municipal yearly average concentration of PM10 calculated as the average of the values measured by i-th monitoring stations	API_PM10^ya=∑_(i=1)^n (AP_(PN	µg/m^3								X					X		
ee23	API_PM10^hae	PM10 hourly average exceedances	X		En-Re-AP*API_PM10^hae*i	Number of yearly exceedances of hourly average limit for PM10 emissions, calculated as the average value of exceedances	API_PM10^hae=∑_(i=1)^n (AP_(P	-	X												X		
ee24	API_PM10	PM10 air pollution index		X	En-Re-AP*API_PM10*I1	First order aggregate index evaluating PM10 emissions	API_PM10=(IAPI_PM10^ya+IAPI_P	-								X					X		
ee25	IAPI_PM10^ya	Normalized PM10 yearly average		X	En-Re-AP*IAPI_PM10^ya*I0	-	MIN-MAX NORMALIZATION	-								X					X		
ee26	IAPI_PM10^hae	Normalized PM10 hourly average exceedances		X	En-Re-AP*IAPI_PM10^hae*I0	-	MIN-MAX NORMALIZATION	-								X					X		
ee27	API_No2	NO2 yearly average	X		En-Re-AP*API_No2*i	Municipal yearly average concentration of NOx calculated as the average of the values measured by i-th monitoring stations	API_NOx=∑_(i=1)^n (AP_(NOx,i)	µg/m^3								X							
ee28	IAP	Atmospheric pollution index		X	En-Re-AP*IAP*I2	Second order aggregate index evaluating atmospheric pollution	IAP=(IAPI_NOX+IAPI_PM10)/2	-								X					X		
ee29	RSP	Percentage of renewable energy production on final energy consumption	X		ES-P*RSP*i	Percentage of renewable energy production on final energy consumption	RSP=∑_(i=1)^n (REP_i^E+R〖EP〗_i	-															
ee30	E_tot	Total yearly energy consumption	X		ES-P*E_tot*i	The yearly energy consumption is calculated as the sum of energy consumption in the different sectors (consumption for water and	E_tot=∑_(j=1)^n 〖Eh_j+Em_j+E_p	MWh								X					X		
ee31	RSG^E	Electrical energy generation from renewable sources	X		ES-P-EL*RSG^E*i	Total electrical energy production from renewable sources	REP^E=∑_(i=1)^n R〖EP〗_i^E	MWh								X					X		
ee32	RSG^T	Thermal energy generation from renewable sources	X		ES_P_TH*RSG^T*i	Total energy production from renewable sources	REP^T=∑_(i=1)^n R〖EP〗_i^T	MWh								X					X		
ee33	IP	Production index		X	ES_P*IP*I1	First order aggregate index accounting for energy generation from renewable sources inside the municipality	IP=(IREP^E+IREP^T)/2	-								X					X		
ee34	RSG	Energy generation from renewable sources	X		ES_P*RSG*i	Total energy production from renewable sources	RSP=∑_(i=1)^n (REP_i,j^E+R〖EP〗_	MWh								X					X		
ee35	PV_cap	Percentage of PV installed capacity out of installable capacity	X		ES-P-EL*PV_cap*i	This indicator is used to evaluate the exploited potential of PV at municipal level	PV_cap=C_(PV,in)/(Cmax_pv)·Po	-								X					X		
ee36	IPGQ	Power grid quality		X	ES-N&S-PG*PVIPGQ*I0	Aggregate index of 1st level which evaluates the quality of power grid by taking into account the number of disconnection and the	IPGQ=0,5·(ID1+IN1)	-								X					X		
ee37	ID1	Normalized_Cumulative_duration_of_disconnection_from_power_grid		X	ES-N&S-PG*ID1*I0	-	MIN-MAX NORMALIZATION	-															
ee38	IN1	Normalized_Average_number_of_disconnection_by_LV_user		X	ES-N&S-PG*IN1*I0	-	MIN-MAX NORMALIZATION	-															
ee39	PGI	Power grid index		X	ES-N&S-PG*PG1*I2	The aggregate index of 2nd level is used to evaluate power distribution grid performance	PGI=0,5·(IPGQ+IPGL)	-								X					X		
ee40	EIT	Energy intensity in tertiary and municipal sectors	X		ES-TU-Te*EIT*i	This indicator is calculated as the ratio between the total consumption in tertiary and municipal sectors, and the total value added in	EIT=(∑_(j=1)^n 〖(Et_j 〗+Em_j))/(∑	MWh/€								X					X		
ee41	EIR_RA	Energy intensity in residential sector - climate corrected	X		ES-TU-Re*EIR_RA*i	This indicator evaluates the total energy consumption of residential sector per amount of residential area. Given that many factors	EIR_RA=(∑_(j=1)^n 〖Er_j ^*〗)/RA	MWh/m^2								X					X		
ee42	IEIR_RA	Normalized energy intensity in residential sector		X	ES-TU-Re*IEIR_RA*I0											X					X		

ee43	Er_j^*	Climate corrected residential enegy consumption	X		ES-TU-Re*Er_j*i		Er_j^*=(Er_j)/(1-σ_heat·(1-τ_(heat,i)))																	see thesis for the parameters involved in
ee44	EIT_cars	Energy intensity in transport sector, private cars only	X		ES-TU-Tr*EIT_cars*i	This indicator is calculated as the sum of enegy consumption for cars, and the total amount of yearly passenger-distance	EIT_cars=(∑_(j=1)^n▒〖Etr_(car,j) 〗	MWh/pkm								X					X			
ee45	PD_tr,car_i	Total passenger-distance travelled by car, i-th fuel	X		ES-TU-Tr*PD_tr,car_i*i	This indicator is evaluated my multiplying the total distance travelled by car fueled by i-th fuel, and the average number of passenger	Pd_(tr,car_i)=D_(tr,car_i)·1,3	pkm								X					X			
ee46	D_(tr,car_i)	Total distance travelled by car, i-th fuel	X		ES-TU-Tr*D_(tr,car_i)*i	This indicator evaluates the total distance travelled by car fuelled with fuel i, by weighting the total distance travelled by cars	D_(tr,car_i)=D_(tr,car)·n_(car_i)/(	km								X					X			
ee47	EIT_pub	Energy intensity in transport sector, public	X		ES-TU-Tr*EIT_pub*i	This indicator is calculated as the sum of enegy consumption for public transport, and the total amount of yearly passenger-distance	EIT_pub=(∑_(j=1)^n▒〖Etr_(pub,j) 〗	MWh/pkm								X					X			Public transport only includes tram, metro and
ee48	Pd_(tr,tram)	Total passenger-distance travelled by tram	X		ES-TU-Tr*Pd_(tr,tram)*i	This indicator is calculated by weighting the total passenger-distance in urban public transport with the percentage of seats	Pd_(tr,tram)=(Pd_(tr,urbp)-Pd_(tr	pkm								X					X			
ee49	Pd_(tr,elbus)	Total passenger-distance travelled by electric buses	X		ES-TU-Tr*Pd_(tr,elbus)*i	This indicator is calculated by weighting the total passenger-distance in urban public transport with the percentage of seats	Pd_(tr,elbus)=(Pd_(tr,urbp)-Pd_(t	pkm								X					X			
ee50	Pd_(tr,gasbus)	Total passenger-distance travelled by natural gas buses	X		ES-TU-Tr*Pd_(tr,gasbus)*i	This indicator is calculated by weighting the total passenger-distance in urban public transport with the percentage of seats	Pd_(tr,gasbus)=(Pd_(tr,urbp)-Pd_(	pkm								X					X			
ee51	Pd_(tr,oilbus)	Total passenger-distance travelled by diesel buses	X		ES-TU-Tr*Pd_(tr,oilbus)*i	This indicator is calculated by weighting the total passenger-distance in urban public transport with the percentage of seats	Pd_(tr,oilbus)=(Pd_(tr,urbp)-Pd_(	pkm								X					X			
ee52	EIT	Energy intensity in transport sector	X		ES-TU-Tr*EIT*i	Total energy consumption from public transport sector and private cars divided by the total amount of passenger-distnce	EIT=(∑_(j=1)^n▒〖Etr_(pub,j) 〗+∑_(j=1)^n▒〖Etr_(car,j) 〗)/(Pd_(tr,tram)+Pd_(tr,elbus)+Pd_(tr,gasbus)+Pd_(tr,oilbus)+Pd_(									X					X			
ee53	IEIT	Normalized energy intensity in transport sector		X	ES-TU-Tr*IEIT*I0		MIN-MAX NORMALIZATION									X					X			
	Bus_euro	Percentage of buses by emission standard class EURO	X		ES-TU-Tr*Bus_euro*I0	The indicator is useful to evaluate atmospheric pollution due to public buses traffic	Bus_euro=(Car_E,j)/(∑_(j=1)^n▒〖Car_E,j〗)									X					X			
ee51	Car_euro	Percentage of cars by emission standard class EURO	X		ES-TU-Tr*Car_euro*I0	The indicator is useful to evaluate atmospheric pollution due to car traffic	Car_euro=(Car_E,j)/(∑_(j=1)^n▒〖Car_E,j〗)									X					X			
ee52	IEIPL	Normalized energy intensity for public lighting		X	ES-TU-O*IEIPL*I0		MIN-MAX NORMALIZATION	-								X					X			
ee53	IWEC	Normalized energy consumption per amount of treated waste		X	ES-TU-O*IWEC*I0		MIN-MAX NORMALIZATION	-								X					X			
ee54	IEI_WAT	Normalized energy intensity of water integrated service		X	ES-TU-O*IEI_WAT*I0		MIN-MAX NORMALIZATION									X					X			
ee55	EIo	Energy intensity in other sector		X	ES-TU-O*EIo*I1	The 1st order aggregate index evaluates the energy intensity of the other sector, by considering public lighting, waste and water	EIo=(IEIpl+IEIwat+IEIw)/3									X					X			
ee56	EIpl	Energy intensity for public lighting	X		ES-TU-O*EIpl*i	This indicator is calculated as the ratio between energy consumption for public lighting and the total number of inhabitants	EIPL=(E_pl·1000)/Pop	kWh/cap								X					X			
ee57	PL_LED%	Percentage of LED used in public lighting sector	X		ES-TU-O*PL_LED%*i	It shows the penetration of LED technology in the public lighting sector	PL_(LED%)=(PL_LED)/(PL_tot)	-								X					X			
ee58	IFU	Final uses index		X	ES-TU-O*IFU*I1		IFU=(IEIT+IEIR_RA+EIO+IEITr)/4																	
ee59	IW̅	Normalized amount_of_consumed_water_per_inhabitant_day		X	Wa_I0		MIN-MAX NORMALIZATION									X						X		
ee60	IWa_distr,loss	Normalized percentage_of_water_losses_in_distribution_system		X	Wa_I0		MIN-MAX NORMALIZATION									X						X		
ee61	IWa_sup	Water supply quality index		X	Wa_I0	The simple index evaluates water supply quality standards	IWa_sup=(IWa_(sup,qual)+IWa_(s	-								X						X		
ee62	EIwat	Energy intensity of water integrated service	X		Wa	This indicator is calculated as the ratio between the total energy consumption for water integrated service (supply, collection,	EIwat=E_(watconsumed)/(Pop_eq	kWh/inhab.eq.								X						X		
ee63	η_(water,nhw)	Percentage of recycled waste in water integrated service	X		Wa	Percentage of recycled non-hazardous waste (N	η_(water,nhw)=(NHW_rec)/NHW	-								X						X		
ee64	Iη_(water,nhw)	Normalized p4ercentage of recycled waste in water integrated service		X	Wa_I0	Percentage of recycled non-hazardous waste (N	MIN-MAX NORMALIZATION	-								X						X		
ee65	GHG_water	GHG emissions per equivalent inhabitant in water integrated service	X		Wa	This indicator is calculated as the ratio between scope 1,2 GHG emissions produced in the urban integrated service and the number	GHG_water=∑_(i=1)^n▒(GHG_wa	tCO_{2eq}/eq.inhab.								X						X		

ee66	IGHG_water	Normalized GHG emissions per equivalent inhabitant		X	Wa_I0		MIN-MAX NORMALIZATION	-								X						X		
ee67	CWD_i	Compliance with water quality discharge standard, i_th pollutant		X	Wa_I0	This index evaluates the compliance with water	IF η<L: CWD_i=1-η_wa,tr_i/L_i; ELS	-								X			X					Limits L_i: DL n.152/2006
ee68	CWD	Compliance with water quality discharge standard		X	Wa_I1	Aggregate index of 1st level which evaluates th	CWD=∑_(i=1)^n (CWD_i)/n	-								X			X					
ee69	AP_water,i	Atmospheric pollutants per inhabitant in water integrated service	X		Wa	Calculated as the ratio between the mass of i-th	AP_(water,i)=m_(pol,wa_i)/(Pop_	t/eq.inhab.								X						X		
ee70	IAP_water,i	Normalized atmospheric pollutants per inhabitant in water integrated service		X	Wa_I0	Calculated as the ratio between the mass of i-th	MIN-MAX NORMALIZATION	-								X						X		
ee71	AP_water	Atmoshperic pollution from water integrated service		X	Wa_I1	Aggregate index of 1st level evaluating the atm	AP_water=∑_(k=1)^n (IAP_(wate	-								X						X		
ee72	IWa	Water Index		X	Wa_I2	Aggregate index of 2nd level evaluating water i	IWa=(IW+Iη_(water,nhw)+IGHG_	-								X							X	
ee73	IRe	Resources index		X	Re_I3	Aggregate index of 3rd level evaluating resourc	IRe=(IW+ILU+IWa)/3	-								X							X	
ee74	CO2_i	Greenhouse gas emissions intensity of energy consumption by sector i	X		GHG	The indicator is calculated as the ratio between energy-related GHG emissions and municipal consumption of energy by sector i.	CO2_i=(GHG_i)/E_(i,j)	t_CO2/MWh																i-th energy sector, j-th energy carrier
ee75	CO2_tot	Global greenhouse gases emissions	X		GHG	The indicator is calculated as the sum of greenhouse gas emissions from the different final use energy sectors	CO2_tot=∑_(i=1)^n [CO2_i]	t_CO2								X					X			
ee76	ICO2_tot	Normalized global greenhouse gases emissions		X	GHG_I0	-	MIN-MAX NORMALIZATION	-																
ee77	IE	Normalized emissions index		X	E_I3	3rd order aggregate index used to evaluate the	IE=(ICO2_tot+IAP)/2																	
ee78	EP_η2	Energy poverty η2	X		We	Energy poverty η2 indicator represents the perc	η_2=1/n_fam ∑_(i=1)^n w_i {I[(s	-								X							X	See thesis for details on the various
ee79	IEP_η2	Normalized_energy poverty η2		X	We_I0			-								X							X	
ee80	EP_η3	Energy poverty η3	X		We	Energy poverty η3 indicator extends the energy	η_3=1/n_fam ∑_(i=1)^n w_i {I[(s	-								X							X	See thesis for details on the various
ee81	GCP	Gross city product	X		We	Calculated as the sum of the total income by gro	GCP=∑_(j=1)^n [TI_J]	€								X						X		
ee82	EI_GCP	Global energy intensity by gross city product	X		We	Calculated as the ratio between total energy co	EI_GCP=(E_tot·10^3)/GCP	MWh/(10^3 €)								X						X		
ee83	EI_Pop	Global energy intensity by inhabitants	X		We	Calculated as the ratio between total energy co	EI_Pop=E_tot/Pop	MWh/inhab								X						X		
ee86	Empl_E&E	Employment in energy&environmental sector	X		J&VA	Calculated as the ratio between the sum of emp	Empl_(E&E)=(Empl_D+Empl_E)/(∑	-								X							X	ATECO classes: D and E
ee86	IEmpl_E&E	Normalized employment in energy&environmental sector	X		J&VA	1st order aggregate index used to evaluate emp	MIN-MAX NORMALIZATION	-								X							X	
ee87	IInv_ener	Normalized investments in energy sector		X	Inv_I0		MIN-MAX NORMALIZATION	-								X							X	ATECO class D
ee88	IInv_pa,env	Normalized public expense for environmental protection		X	Inv_I0		MIN-MAX NORMALIZATION	-								X							X	Coicop class 14.6.3
ee89	Inv_E&E	Investments and expenses in energy&environmental sector		X	Inv_I1	1st order aggregate index used to evaluate inve	Inv_(E&E)=(IInv_D+IInv_(pa,env))/	-								X							X	
ee90	VA_E&E	Value_added_in_energy&environmental_sectors		X	Inv_I0		VA_(E&E)=∑_(i=1)^n [VA_i]	-								X							X	ATECO classes: D and E
ee91	I_VA_E&E	Normalized_value_added_in_energy&environmental_sectors		X	Inv_I0		MIN-MAX NORMALIZATION	-								X							X	
ee92	I_J&VA	Jobs and value added index			J&VA_I1		I_J&VA=(IEmpl_E&E+IVA_E&E)/2																	
ee93	Iwe	Wealth index		X	We_I2	2nd order aggregate index used to evaluate we	I_we=(IInv_(E&E)+IJ&VA+IEP_η2)/	-								X							X	

3. **Python script for analysis of the dataset "Dettaglio attestato di prestazione energetica (APE) – sezione impianti"**

```
# -*- coding: utf-8 -*-
"""
Created on Thu Aug 25 12:36:03 2022
@author: Carlo
"""
import pandas
import numpy as np
pandas.set_option('display.max_columns', None) #to see all columns using head
pandas.set_option('display.max_rows', None) #to see all rows using head
file=pandas.read_csv('regpie-Sicee_v_datigen_impianti_v2_8399-all.csv', sep=";")
aa=file.describe()
turin=file[(file.desc_comune=="TORINO")] #filtra 120otenza Torino
labels=list(turin.columns.values)
residential=turin['flg_residenziale'].value_counts()
turin_res=turin.query("flg_residenziale=='S'") #extract Turin residences
plant_type=turin_res['serv_ener'].value_counts()

# estrai le abitazioni usate in modo continuativo

type_of_use=turin_res['descr_destinazione_uso'].value_counts()
turin_res=turin.query("descr_destinazione_uso=='Abitazioni adibite a residenza con carattere
continuativo, quali abitazioni civili e rurali'")
turin_res_cl_inv=turin_res.query("serv_ener=='<sezioneClimaInver>'") #estrai impianti clima
invernale
categoria_impianto=turin_res_cl_inv['tipo_impianto'].value_counts() #conta impianti
categoria_combustibile_winter=turin_res_cl_inv['combustibile'].value_counts() #conta tipo
combustibili

#valutazione impianti termici uso invernale ad energia elettrica,gas,teleriscaldamento

gas_winter=turin_res_cl_inv.query("combustibile=='Gas naturale'")
categoria_impianto_gas_winter=gas_winter['tipo_impianto'].value_counts()
dh_winter=turin_res_cl_inv.query("combustibile=='Teleriscaldamento'")
categoria_impianto_dh_winter=dh_winter['tipo_impianto'].value_counts()
elettrica_winter=turin_res_cl_inv.query("combustibile=='Energia elettrica'")
categoria_impianto_elettrica_winter=elettrica_winter['tipo_impianto'].value_counts()

#sezione impianti combinati

energy_service=turin_res['serv_ener'].value_counts()
turin_res_combined_plants=turin_res.query("serv_ener=='<sezioneImpiantiCombinati>'")
#estrai impianti combinati
categoria_combustibile_combined=turin_res_combined_plants['combustibile'].value_counts()
#conta tipo combustibili
#find residences with both combined plants and winter heating plants
```

```
inter_comb_wint=pandas.Series(list(set(turin_res_cl_inv[‘id_certificato’]) & set(turin_res_combined_plants[‘id_certificato’])))

#sezione acqua calda

turin_res_hot_water=turin_res.query(“serv_ener==’<sezioneAcquaCalda>’”) #estrai impianti acqua calda
categoria_combustibile_hot_water=turin_res_hot_water[‘combustibile’].value_counts() #conta tipo combustibili
inter_hw_wint=pandas.Series(list(set(turin_res_cl_inv[‘id_certificato’]) & set(turin_res_hot_water[‘id_certificato’])))
inter_hw_combined=pandas.Series(list(set(turin_res_hot_water[‘id_certificato’]) & set(turin_res_combined_plants[‘id_certificato’])))
elettrica_hot_water=turin_res_hot_water.query(“combustibile==’Energia elettrica’”)
categoria_impianto_elettrica_hot_water=elettrica_hot_water[‘tipo_impianto’].value_counts() #conta impianti

#import pdc dictionary as a list

with open(‘dizionario_pdc.txt’, ‘r’) as f:
myNames = [line.strip() for line in f]
elettrica_winter[‘flagCol’] = np.where(elettrica_winter.tipo_impianto.str.contains(‘|’.join(myNames),False),1,0)
elettrica_winter_filter_hp=elettrica_winter.query(“flagCol==1”)
elettrica_winter_filter_hp=elettrica_winter_filter_hp.dropna(axis=0,subset=[‘tipo_impianto’])
hp_power=elettrica_winter_filter_hp.potenza_nomin_kw

#sezione clima estivo

turin_res_summer=turin_res.query(“serv_ener==’<sezioneClimaEst>’”)
categoria_combustibile_summer=turin_res_summer[‘combustibile’].value_counts() #conta tipo combustibili
gas_summer=turin_res_cl_inv.query(“combustibile==’Gas naturale’”)
categoria_impianto_summer=gas_summer[‘tipo_impianto’].value_counts() #conta impianti

#sezione rinnovabili

turin_res_renewable=turin_res.query(“serv_ener==’<sezioneProdFontiRinn>’”)
categoria_combustibile_renewable=turin_res_renewable[‘combustibile’].value_counts() #conta tipo combustibili
turin_res_renewable_solar_thermal=turin_res.query(“combustibile==’Solare termico’”)
inter_hw_solarthermal=pandas.Series(list(set(turin_res_hot_water[‘id_certificato’]) & set(turin_res_renewable_solar_thermal[‘id_certificato’])))
```

4. Reference energy system for the City of Turin

The Reference Energy System (RES) is a diagram useful to schematize the structure of the energy system for a given geographical area (country, region, municipality), by describing the energy flows and the involved technologies and activities. In particular, the RES shows the energy flows from primary energy sources to end-uses in the different sectors, allowing one to analyse the whole supply-demand chain.

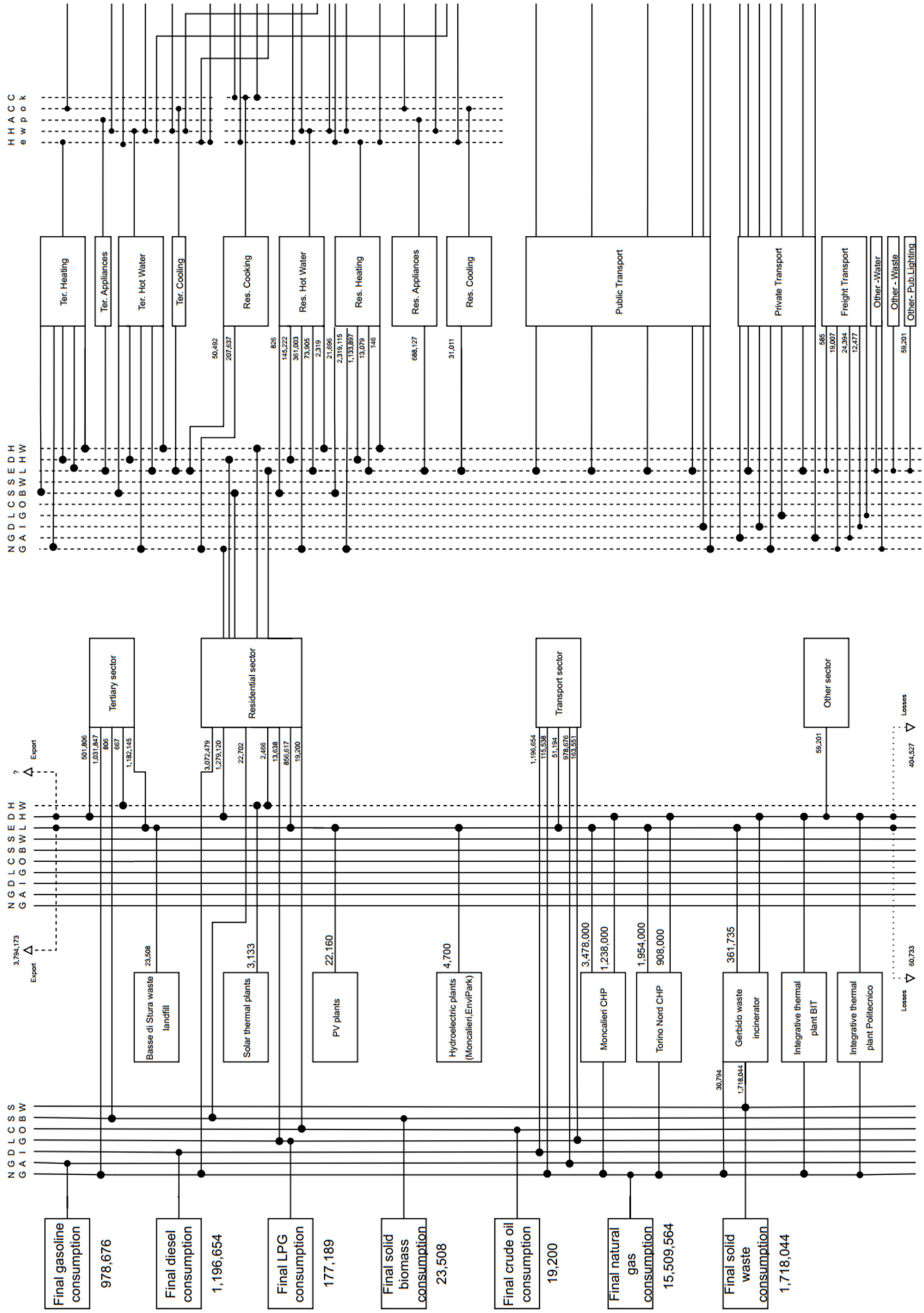
The RES is usually built schematizing, from left to right, the following elements:

- *Primary energy sources*: this section reports the input fuel for the area of analysis (e.g. crude oil, imported electricity, natural gas, biomass…)
- *Processes*: this layer contains processes which modify primary energy sources (e.g. refinery of crude oil).
- *Conversion Technologies*: primary energy sources are sent to conversion technologies used for delivering energy carriers (e.g. electricity, heat). Examples of conversion technologies include large plants such as CHP stations.
- *Distribution systems*: this layer include systems used for delivering energy such as power grid, natural gas distribution networks and district heating networks.
- *End-uses technologies*: this layer is used to schematize energy conversion technologies at lower scale, including, for example, modular natural gas burners for domestic heating, solar collectors and vehicles.
- *Useful energy demand*: energy necessary for final applications, like energy for domestic heating or passenger transport. The useful energy demand can be reduced by means of energy conservation measures (like high-level insulation for the residential sector) and is used to deliver energy services (like lighting, heated area, domestic hot water).

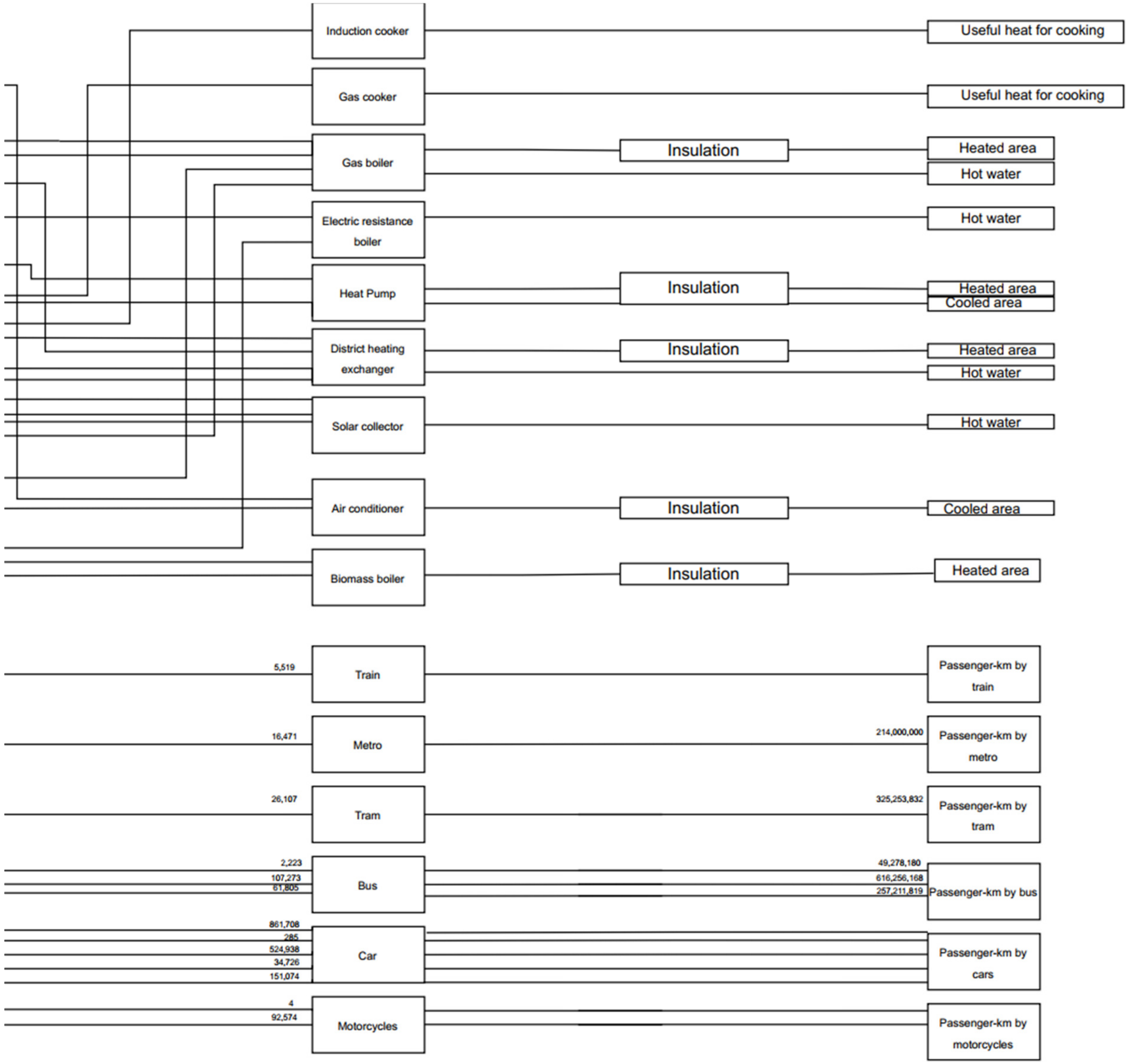
In the version of the Turin RES reported below, this structure has been modified, to take into account the peculiarities of cities' energy system, and simplified, as not all energy flows are described. Furthermore, the scheme is complemented with values of energy flows [MWh], providing also information typical of tabular energy balances.

RES is characterized by nodes (squares) and branches (horizontal lines) which are connected to vertical lines representing, in the case of continuous lines, real infrastructures for transport/distribution of energy commodities and, in the case of dashed lines, a schematic tool to aggregate energy commodities (or end-uses) and simplify the representation. It has to be noted that power grid and district heating losses values are based respectively on losses' values reported by local low-voltage network administrator and GSE dataset Atlaimpianti. Values for import/export of energy have been calculated for electricity only and not for district heating, since data regarding thermal generation of two large plants in the area are missing.

Moving from left to right, the first layer contains primary energy sources used in the municipality, plus other fuels (like gasoline and diesel oil) which are also considered to be primary energy sources; indeed, the *Processes* layer has not been reported as it is not relevant for describing the energy flows at municipal level. Primary energy sources also contains the amount of solid waste delivered to local waste incinerator, whose energy content has been evaluated through low-calorific value provided by the company administrating local waste incineration plant. The second layer shows then conversion technologies; in this case it has been also considered the production technologies from distributed energy resources, like PV plants and solar thermal plants (which, in case of large installations could be used for district heating purposes). At the present moment, the value of produced energy for solar thermal plants is only related to small private plants used for domestic hot water production. The third layer represents the end-use sectors categorized in Tertiary, Residential, Transport and Other sectors following the same rules of classification explained in paragraph 2.5, whereas a further sub-classification for each sector is reported in the fourth layer. The fifth layer contains main end-uses technologies for each sector whereas the sixth layer shows the energy services provided by each technology. For the transport sector, the measurement unit for the reported values is [passenger km].



Final gasoline consumption
978,676
Final diesel consumption
1,196,654
Final LPG consumption
177,189
Final solid biomass consumption
23,508
Final crude oil consumption
19,200
Final natural gas consumption
15,509,564
Final solid waste consumption
1,718,044
Basse di Stura waste landfill
Solar thermal plants
3,133
PV plants
22,160
Hydroelectric plants (Moncalieri,EnviPark)
4,700
Moncalieri CHP
3,478,000
1,238,000
Torino Nord CHP
1,954,000
908,000
Gerbido waste incinerator
361,735
Integrative thermal plant BIT
Integrative thermal plant Politecnico
Export
Losses
Tertiary sector
Residential sector
Transport sector
Other sector
Ter. Heating
Ter. Appliances
Ter. Hot Water
Ter. Cooling
Res. Cooking
Res. Hot Water
Res. Heating
Res. Appliances
Res. Cooling
Public Transport
Private Transport
Freight Transport
Other -Water
Other - Waste
Other- Pub.Lighting



Legend

NG Natural Gas

GA Gasoline

DI Diesel

LG Liquefied Petroleum Gas

CO Crude Oil

SB Solid Biomass

SW Solid Waste

EL Electricity

DH District Heating