Politecnico di Milano
School of Architecture, Urban Planning and Construction Engineering
Master of Science in Urban Planning and Policy Design

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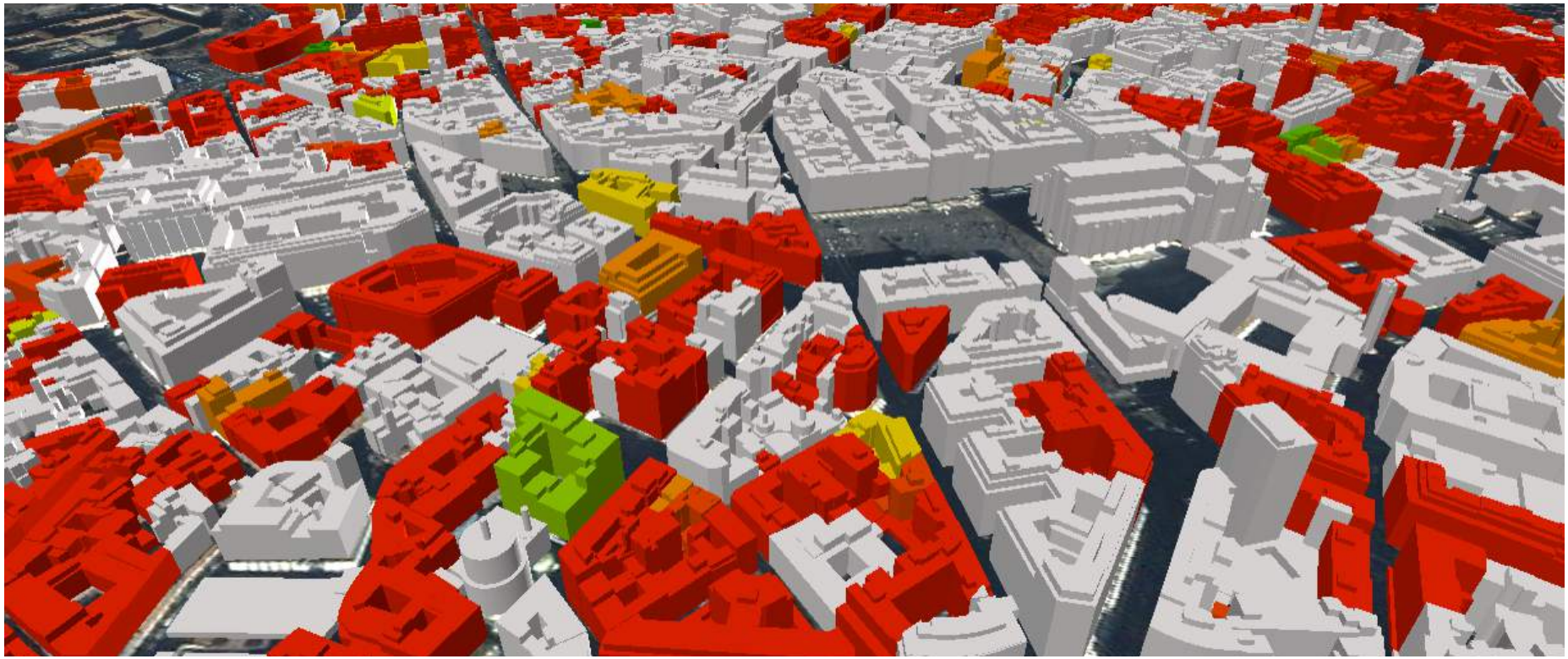
Geographic Information Systems based open data visualization for supporting energy efficiency strategies in the residential sector: An application in the Metropolitan City of Milan, Italy



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Co-supervisor: dr. Gabriela Fernandez

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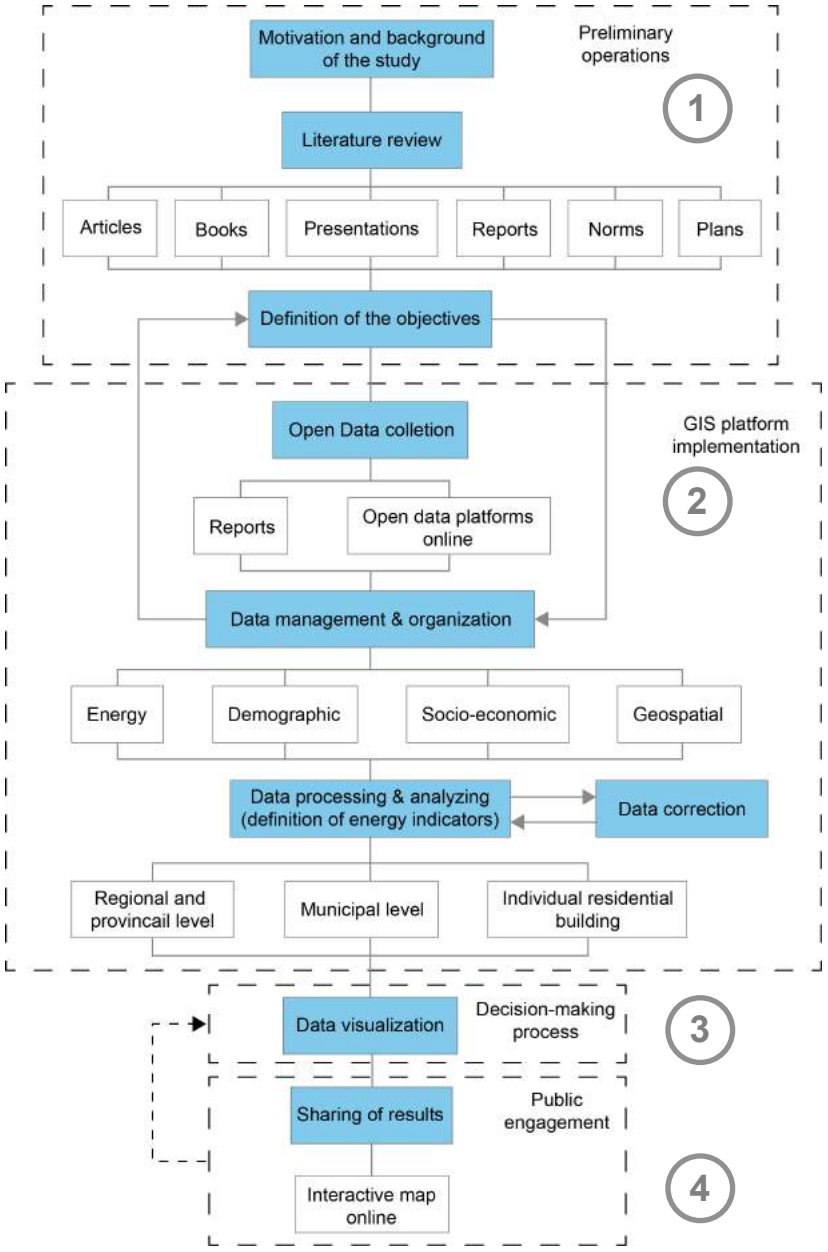
Matricola: 816581

April 2016

Methodology



The research can be divided into four phases, and the first three were realized in the thesis.

Energy issues

1. Italy: mainly relied on importation (Energy supply security 2014 Italy, IEA).
2. Lombardy: severe energy shortage (Fasano M., 2015).
3. Residential sector (Lombardy): one third of the Lombardy's final energy consumption in 2013 (SIRENA20).

Objectives

The thesis intends to provide scientific support to policy makers in the residential sector in the Metropolitan City of Milan from different scales for:

1. understanding energy consumption trend;
2. identifying the energy efficiency;
3. prioritizing renovation actions.

Method

1. Tremendous open data (freely available to everyone, without restrictions) analysis.
2. Geographic Information Systems as a powerful data visualization tool.

Facing energy consumption issue by legislations and planning tools

Directive 2002/91/EC
16 December 2002
Concept of energy certification of buildings

Directive 2010/31/EU
19 May 2010
Energy performance of buildings
Nearly zero-energy building

Directive 2009/28/EC (20-20-20)
23 April 2009
20-20-20 targets by 2020

National Energy Strategy
8 March 2013
Energy policy guideline of Italy

Plan for a Sustainable Lombardy
10 February 2010
Building a low carbon and high energy efficiency Region

Regional Evironmental Energy Planning
12 June 2015
Energy saving and developement of renewable energy sources (RESs)

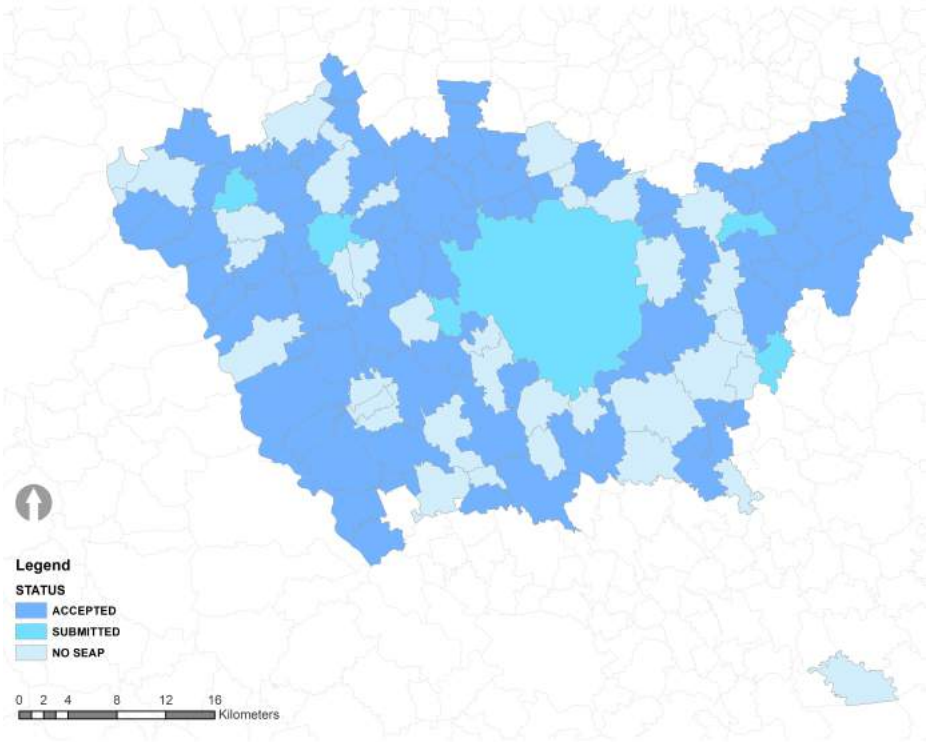
Milano
Comune di Milano

Municipal Energy Plan
Population over 50,000

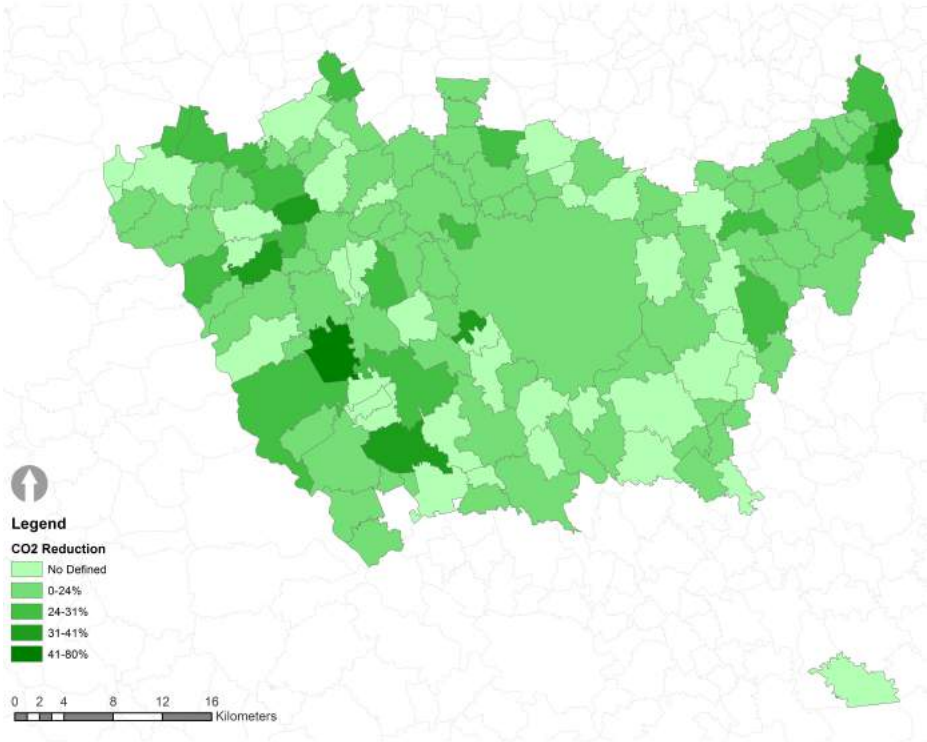
Sustainable Energy Action Plan
18 December 2008 (Municipality of Milan)
A tool proposed by European Commission
20% CO2 reduction target by 2020

Sustainable energy action plan (SEAP)

Status of the Sustainable Energy Action Plan in the Metropolitan City of Milan



Signatories with different targets of CO2 reduction by 2020 in the Metropolitan City of Milan



Data source: Covenant of Mayors, as of March 2016. Elaborated by the author.

The national energy balance of Italy report

- Primary energy consumption: the direct use at the source, or supply to users without transformation, of crude energy, that is, energy that has not been subjected to any conversion or transformation process

- Final energy consumption: all energy supplied to the final consumer for all energy uses, usually including consumption in household, tertiary, transport, agriculture, industry, non-energy uses, and bunkering.

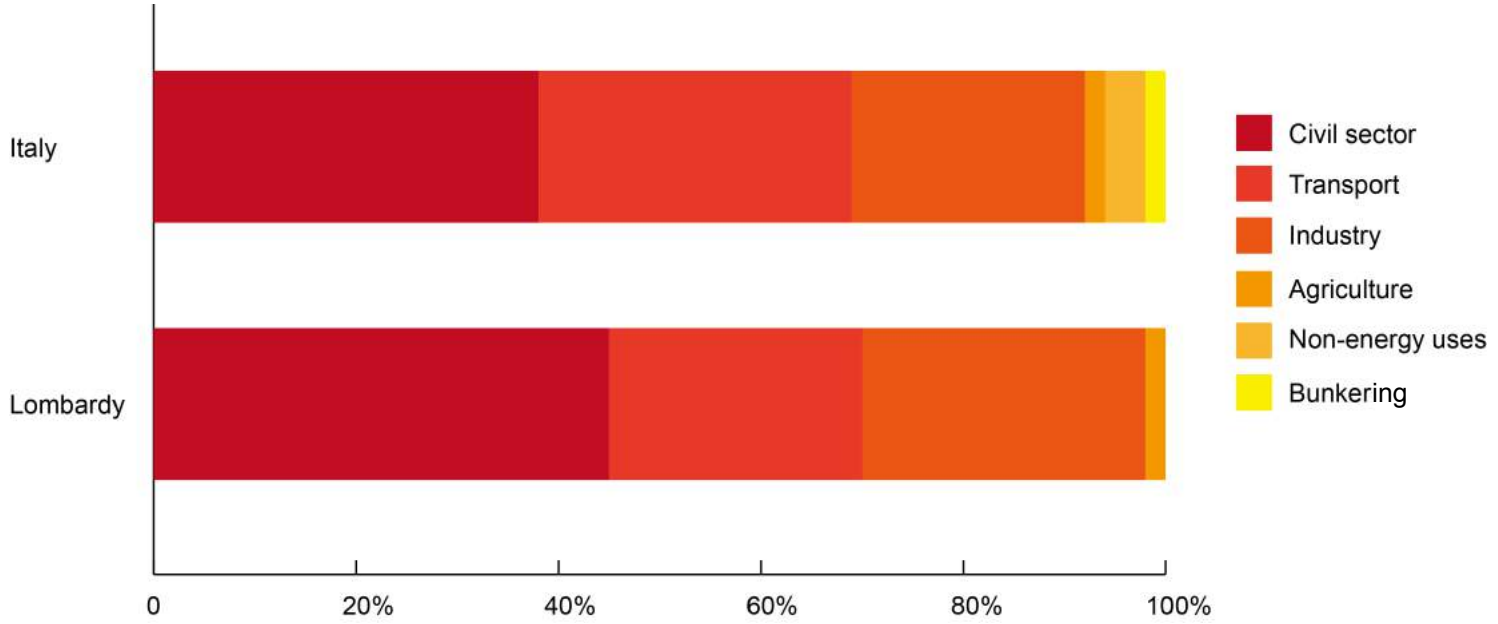
Tab. Primary energy consumption by sources and their further disaggregation

Energy consumption by source in 2013 (ktoe)	Primary consumption	Final consumption	Production of electricity	Consumption and losses of energy sector
Oil	58,970	51,929	3,017	4,024
Natural gas	57,387	38,185	17,670	1,532
Renewable	30,783	6,310	24,466	8
Solid fuels	14,622	3,176	11,292	154

Source: National Energy Balance – Ministry of Economic Development, 2013

Comparison of final energy consumption by sector between Italy and Lombardy region in 2013

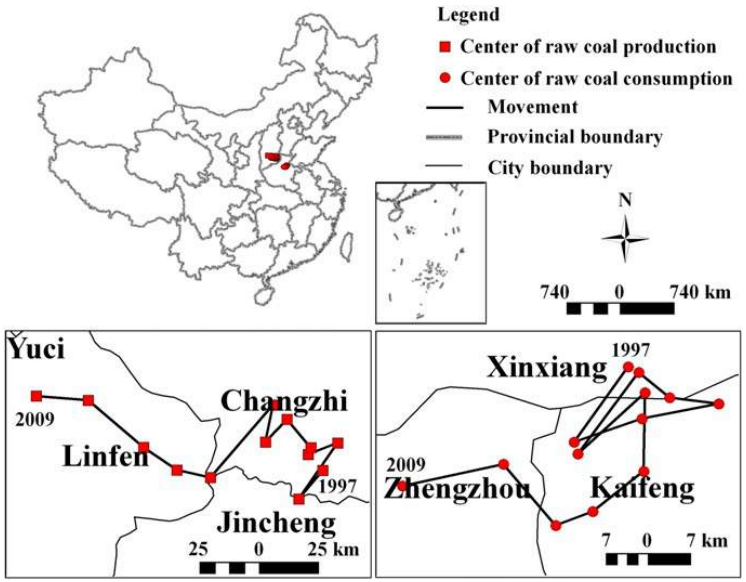
- Italy and Lombardy region have very different energy consumption structure.
- Only civil sector (household & tertiary) in Lombardy region accounted almost half of the total final energy consumption.



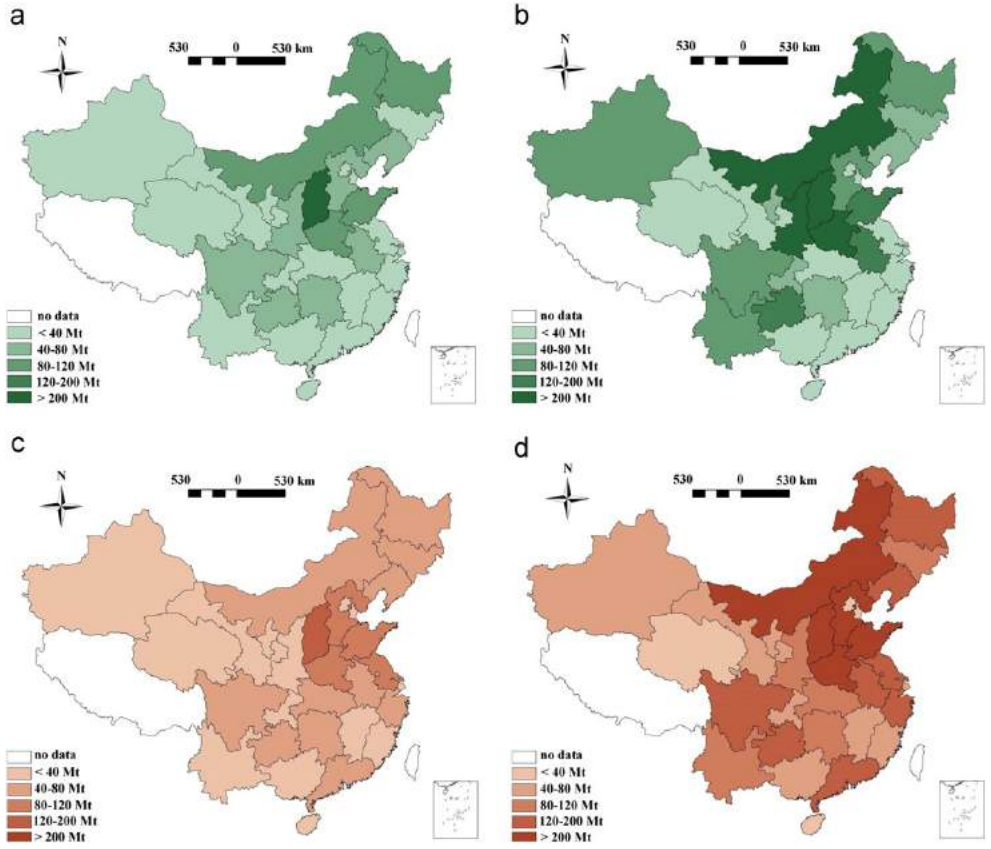
Data source: National energy balance report & SIRENA20, as of 2013. Elaborated by the author.

Case study

Centers of gravity model for analyzing the distribution and evolution of energy supply and demand in China (Zhang et al., 2012)



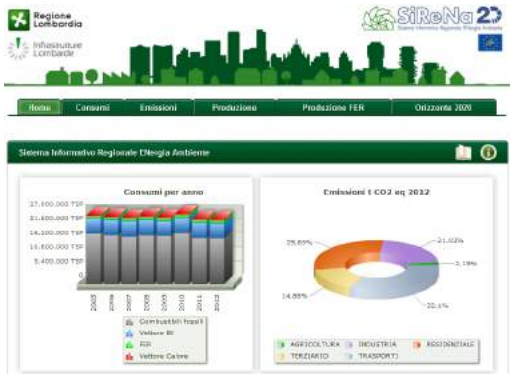
Changes in the centers of gravity for raw coal production and consumption in China from 1997 to 2009



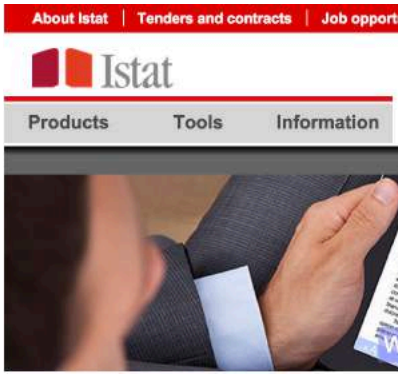
Spatial pattern of raw coal (a,b) supply and demand (c,d) in China in (a,c) 1997 and (b,d) 2009

Open data platforms

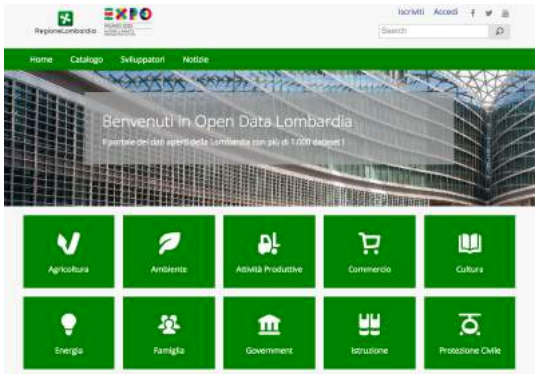
SIRENA20 (energy consumption)



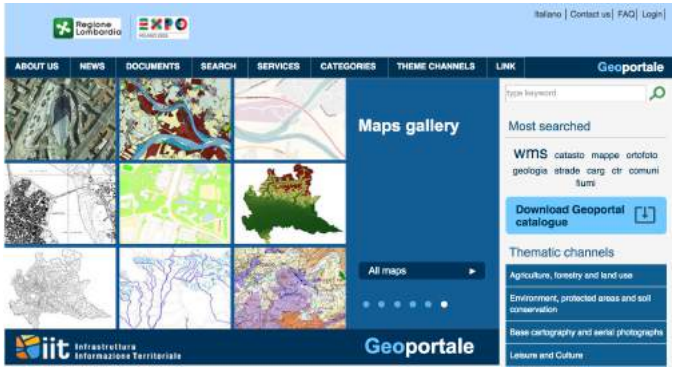
Istat (population)



Open Data Lombardia (energy certificates)



Geoportale Lombardia (geospatial data)



Immobiliare.it (socio-economic data)

CENED (energy certificate of the buildings) database and its reorganization

CENED
Certificazione ENergetica degli EDifici

Source: www.cened.it

Name field	Description	Note
INDIRIZZO	Address of the building which is the object of energy certification	To locate each single EPC
PROVINCIA		To select EPCs that belong to Metropolitan City of Milan
COMUNE		To select EPCs that belong to each municipality
DESTINAZIONE_DI_USO	Use of the building according to DPR 412/1993	To select buildings for residential uses
ANNO_COSTRUZIONE	Year of construction of the building	To verify the correlation between energy efficiency of building and its year of construction.
MOTIVAZIONE_APE	For which motivation the EPC was released	To understand why people do the energy performance certification which may reflect some interesting points
CLASSE_ENERGETICA	Energy class of the building	To evaluate the energy efficiency of the building
DATA_CHIUS	The date of accomplishment of the EPC	To identify the total number of EPCs accomplished in a specific period
SUPERFICIE_NETTA	The net area of each dwelling	To calculate the total floor area with EPC in each municipality
EPH	Primary energy demand for unit indoor space heating in a year (kWh/m^{2}year).	To calculate the total energy demand for heating of a dwelling

The research was performed at three different levels in order to evaluate comprehensively the residential sector from an energy point of view:

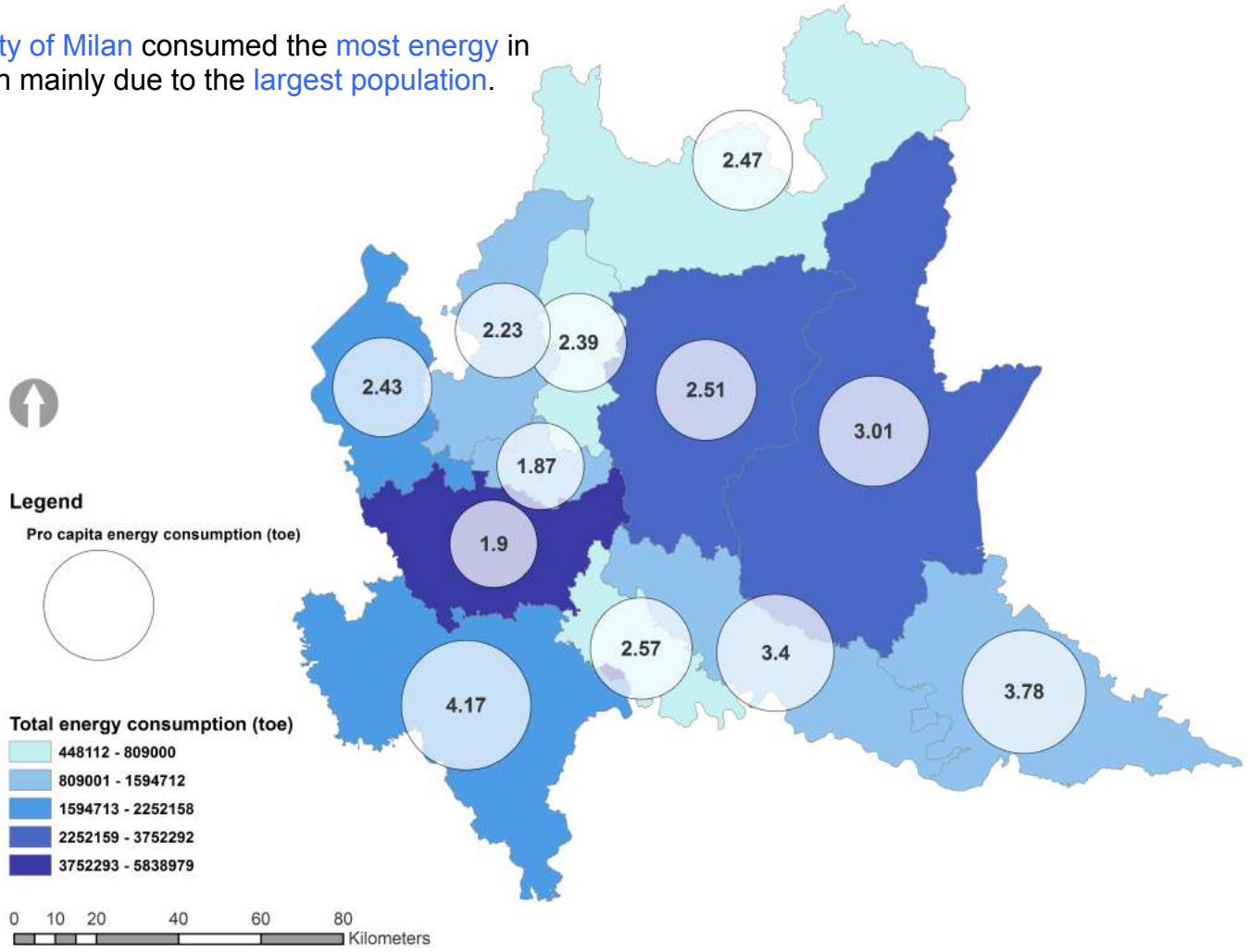
1. Regional and provincial level - centers of gravity method - understanding energy consumption tendency in the residential sector in the Lombardy region.

2. Urban level - weighted average method - identifying the average energy efficiency of residential sector in the 134 municipalities in the Metropolitan City of Milan.

3. Building level – geospatial location - identify the energy class of the residential buildings and prioritize renovation in terms of energy efficiency as well as their historical, architectural and cultural values.

Final energy consumption and territory

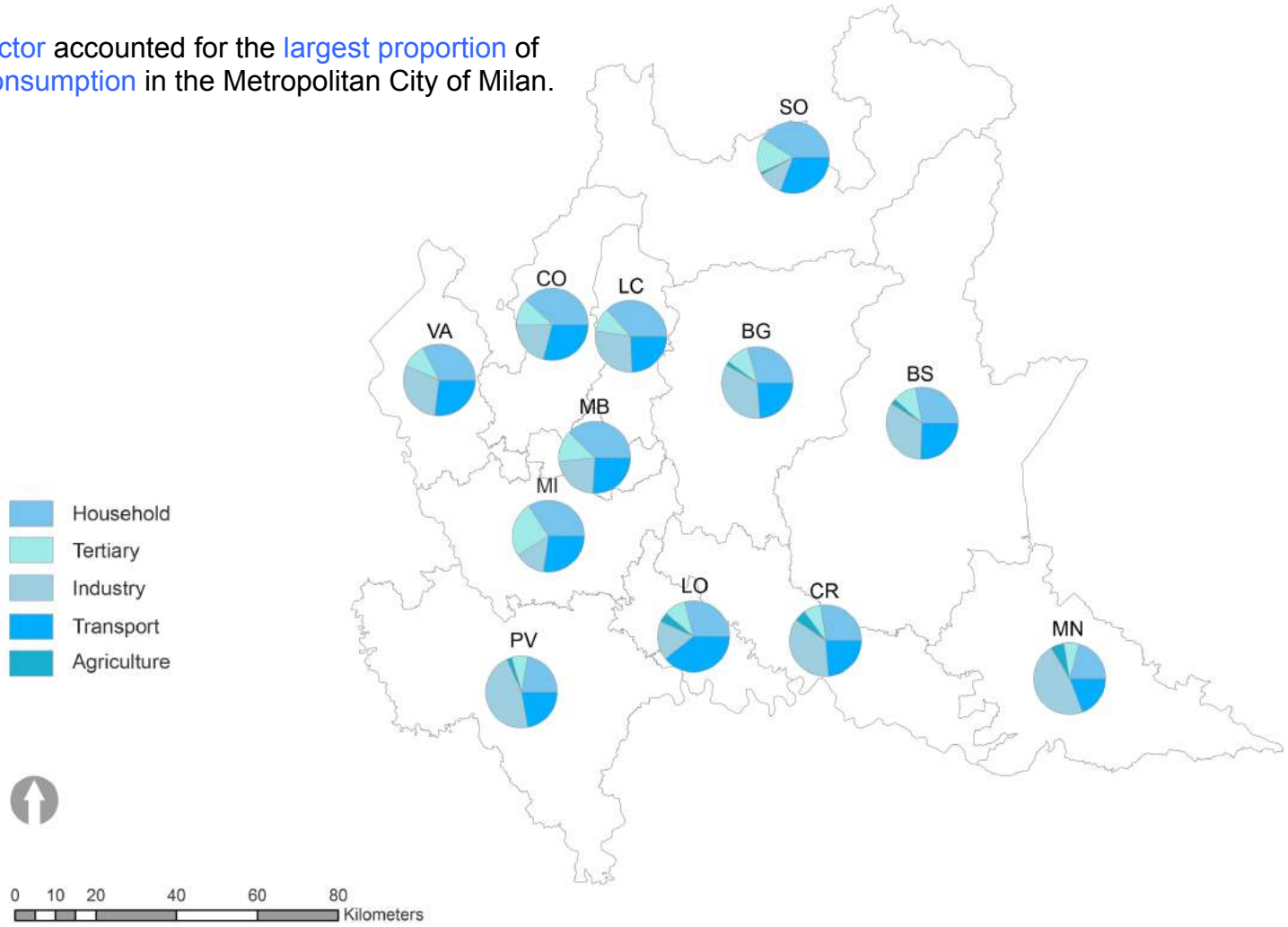
The Metropolitan City of Milan consumed the most energy in the Lombardy region mainly due to the largest population.



Data source: SIRENA20 & Istat, as of 2012. Elaborated by the author.

Final energy consumption and territory

Residential sector accounted for the largest proportion of final energy consumption in the Metropolitan City of Milan.



Data source: SIRENA20 & Istat, as of 2012. Elaborated by the author.

Method: Centers of gravity analysis of the residential energy consumption tendency

Assumption:
- A homogeneous plane;
- Energy consumption concentrates in the provincial capital cities.

Input data:
- Energy consumption data in each province from 2005 to 2012 (SIRENA20).
- The coordinates of the 12 provincial capital cities (GIS calculation).

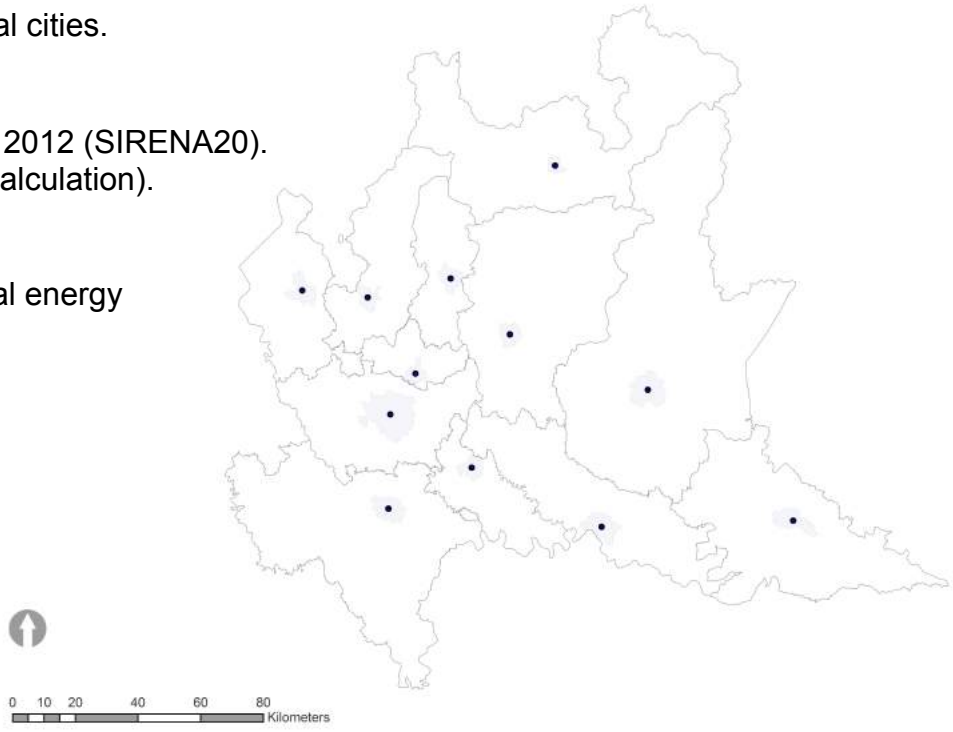
Output data:
- The coordinates of the centers of gravity of the residential energy consumption from 2005 to 2012.

$$X_t = \frac{\sum M_{ti} x_i}{\sum M_{ti}}$$

$$Y_t = \frac{\sum M_{ti} y_i}{\sum M_{ti}}$$

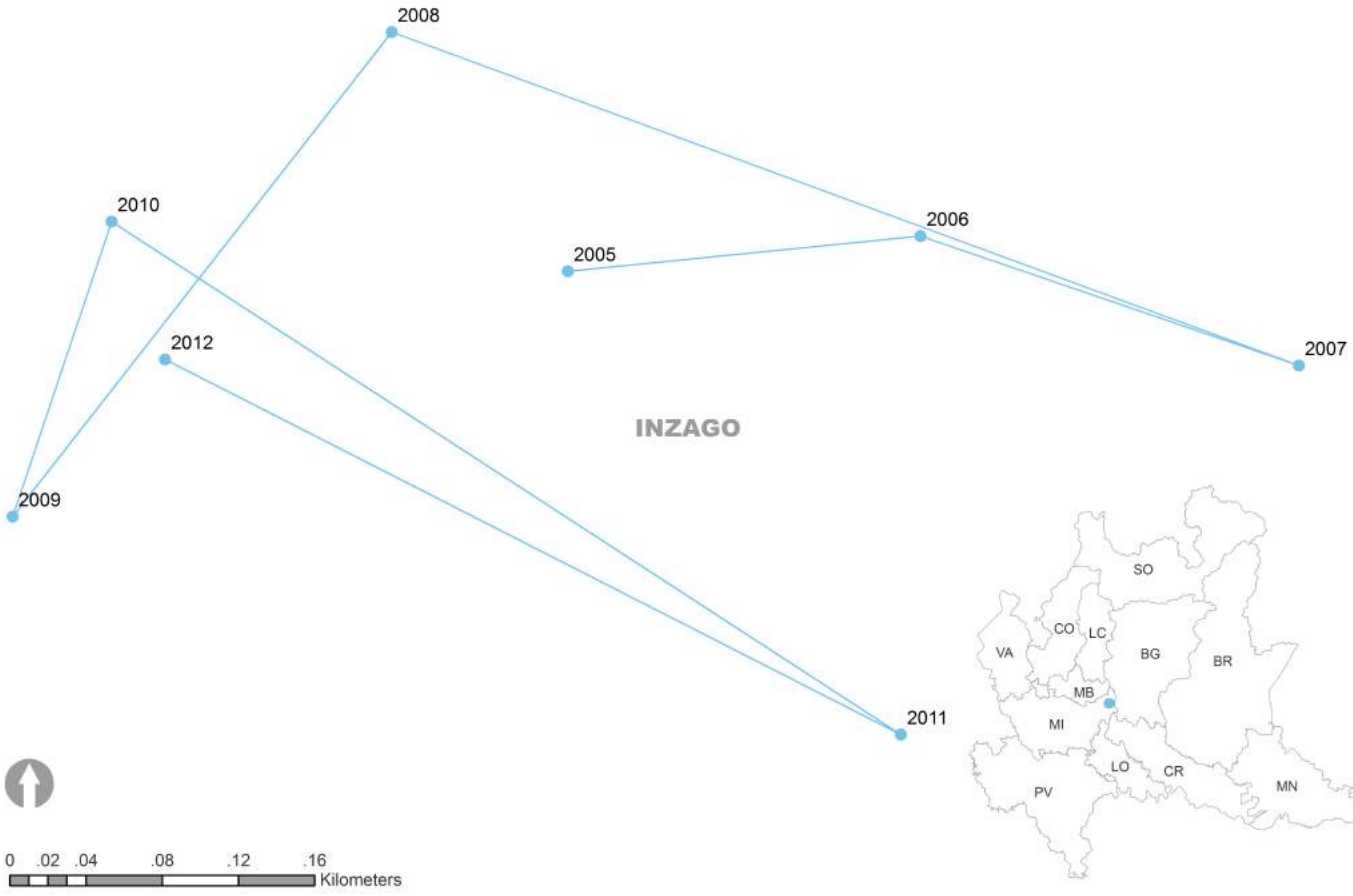
where

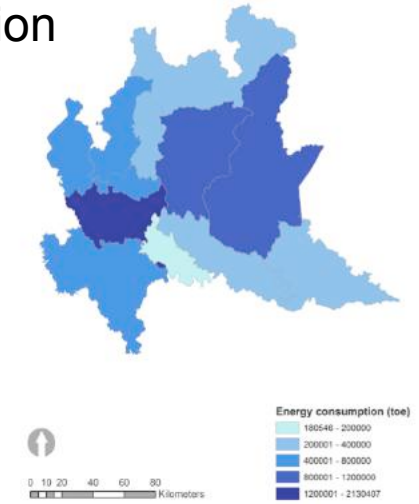
- X_t and Y_t represent the longitude and latitude coordinates of the center of gravity in year t;
- M_{ti} represents the amount of energy consumption by province i in year t;
- x_i and y_i represent the longitude and latitude coordinates of the capital city of province i.



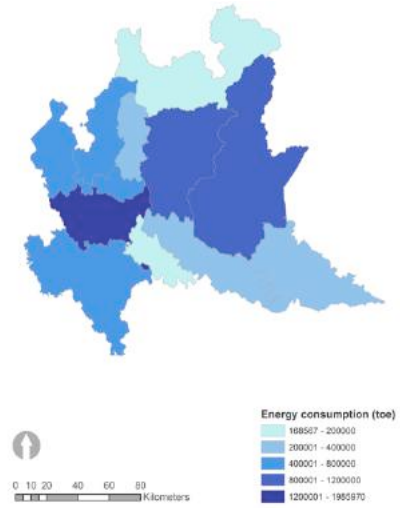
Changes in the centers of gravity of residential energy consumption

Overall movement from 2005 to 2012:
Direction: southwest Movement distance: 216m Location: Metropolitan City of Milan





Residential energy consumption, as of 2005



Residential energy consumption, as of 2012

Data source: SIRENA20. Elaborated by the author.

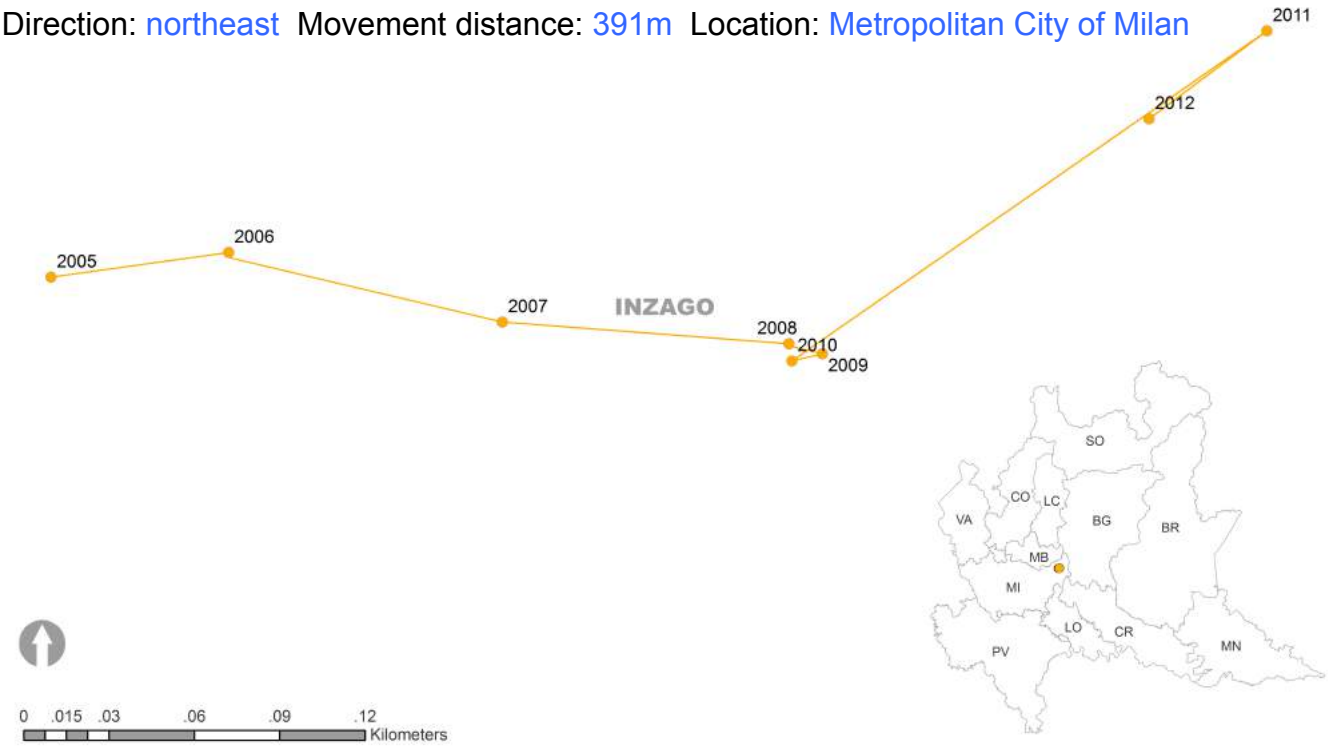
Energy efficiency and residential sector – Regional and provincial level

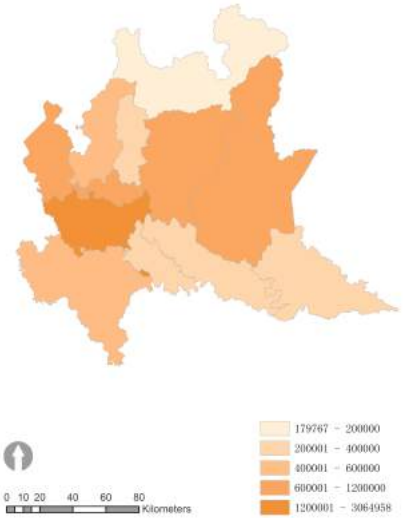
Changes in the centers of gravity of population

Input data:
- Population in each province from 2005 to 2012 (Istat).
- The coordinates of the 12 provincial capital cities (GIS calculation).

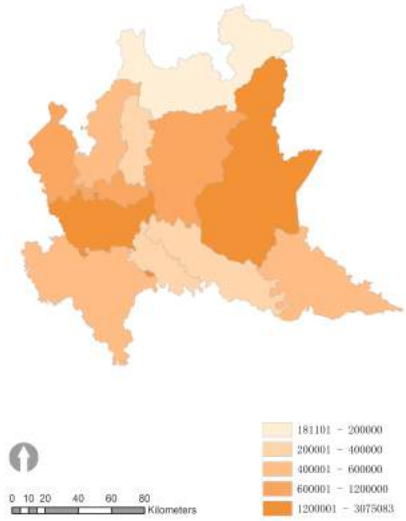
Output data:
- The coordinates of the centers of gravity of the population from 2005 to 2012.

Overall movement from 2005 to 2012:
Direction: northeast Movement distance: 391m Location: Metropolitan City of Milan





Population, as of 2005



Population, as of 2012

Data source: Istat. Elaborated by the author.

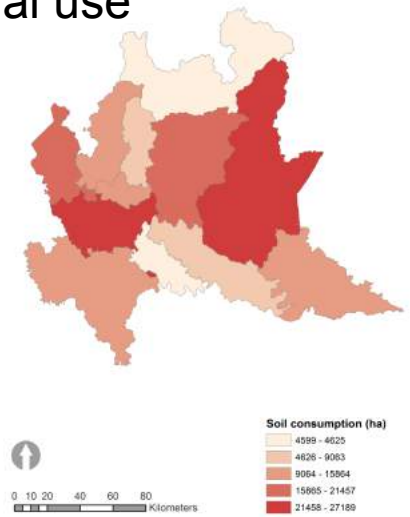
Changes in the centers of gravity of soil consumption for residential use

Input data:
- Soil consumption for residential use in 2007 and 2012 (DUSAF).
- The coordinates of the 12 provincial capital cities (GIS calculation).

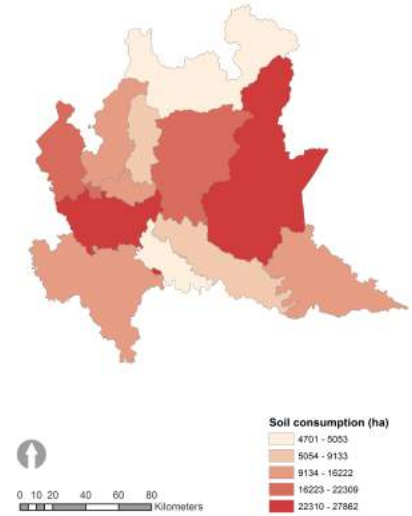
Output data:
- The coordinates of the centers of gravity of the soil consumption for residential use from 2007 to 2012.

Overall movement from 2007 to 2012:
Direction: northeast Movement distance: 218m
Location: Province of Bergamo

Data source: DUSAF. Elaborated by the author.

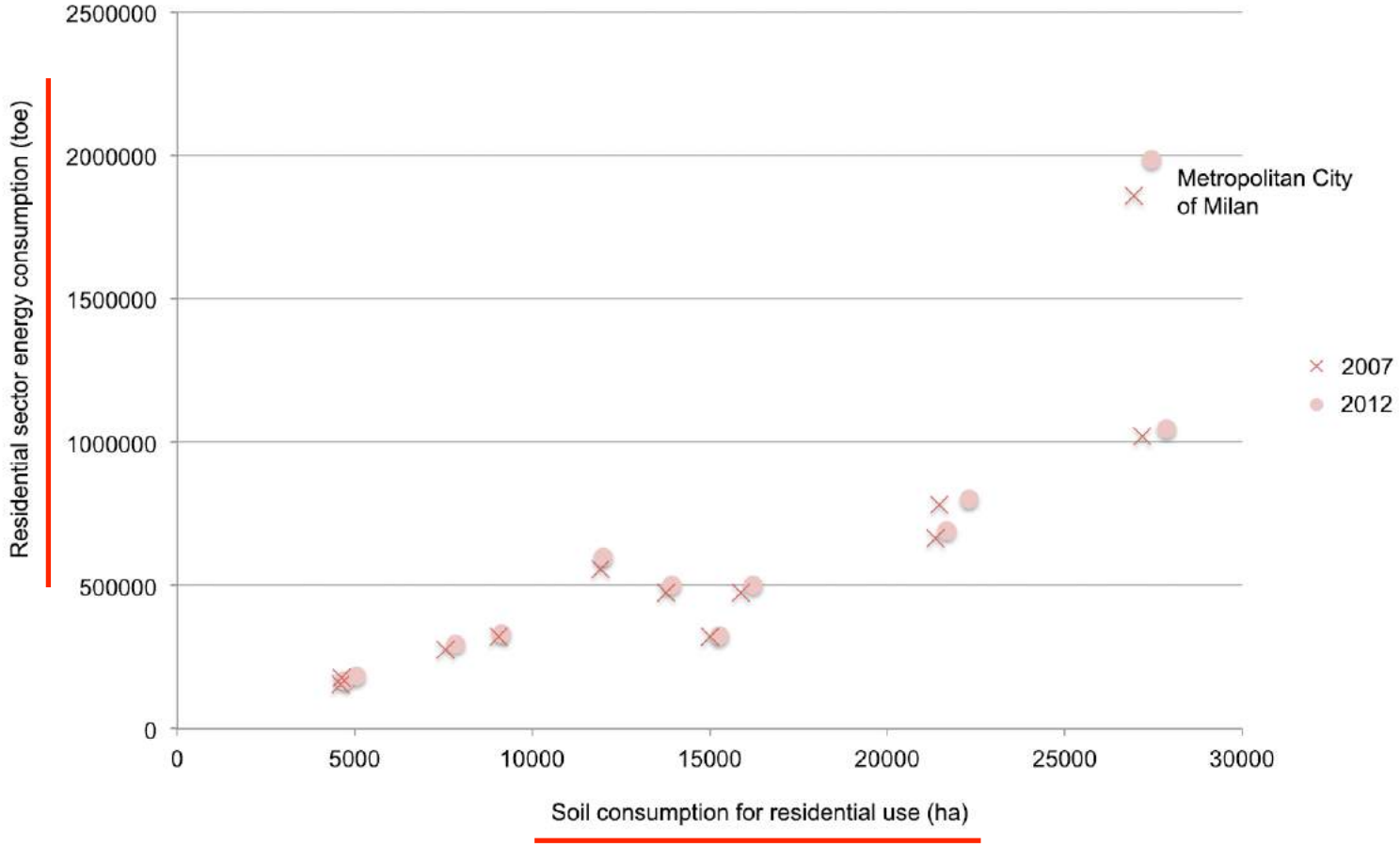


Soil consumption for residential use, as of 2007



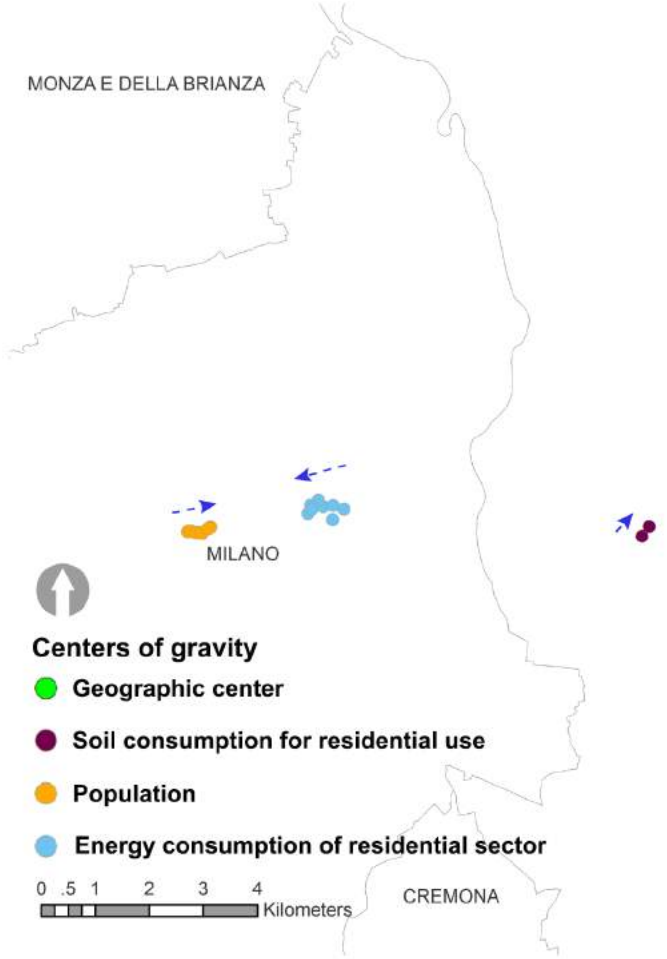
Soil consumption for residential use, as of 2012

Correlation between soil consumption for residential use and residential sector energy consumption



Data source: DUSAF & SIRENA20. Elaborated by the author.

All centers of gravity analyzed and geographic gravity of Lombardy

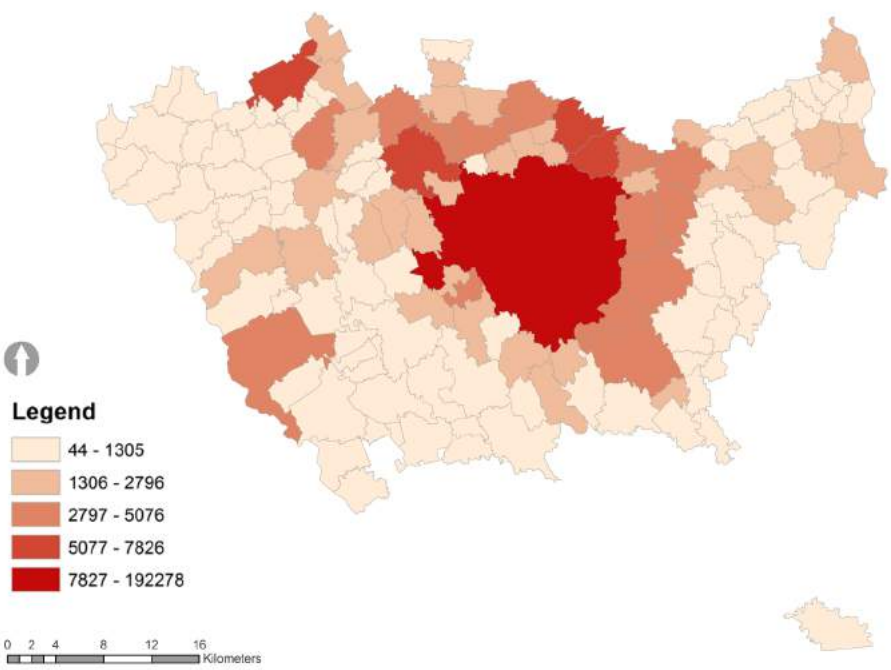


- Centers of gravity of residential sector's energy consumption always remained in the Metropolitan City of Milan and moved continuously towards the southwest;
- Centers of gravity of soil consumption for residential use and population moved towards northeast, which were opposite to that of energy consumption and revealed the energy efficiency issue in the residential sector.

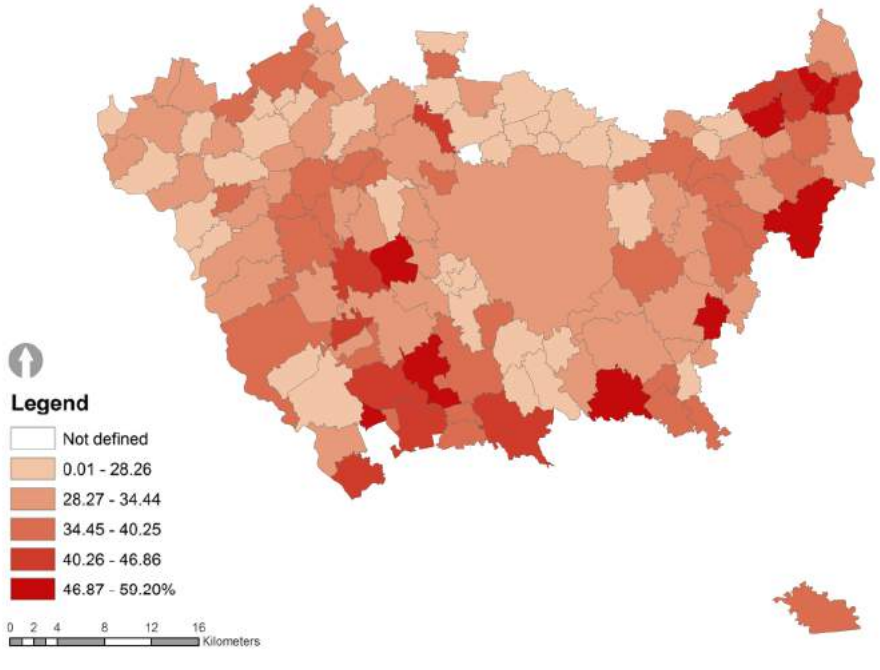
The spatial distribution of Energy Performance Certificates (EPC)

Approximately 392,903 EPCs, which accounted for about 32% of the entire dwellings, were issued in the Metropolitan City of Milan by the end of September, 2015.

The distribution of EPCs in the Metropolitan City of Milan



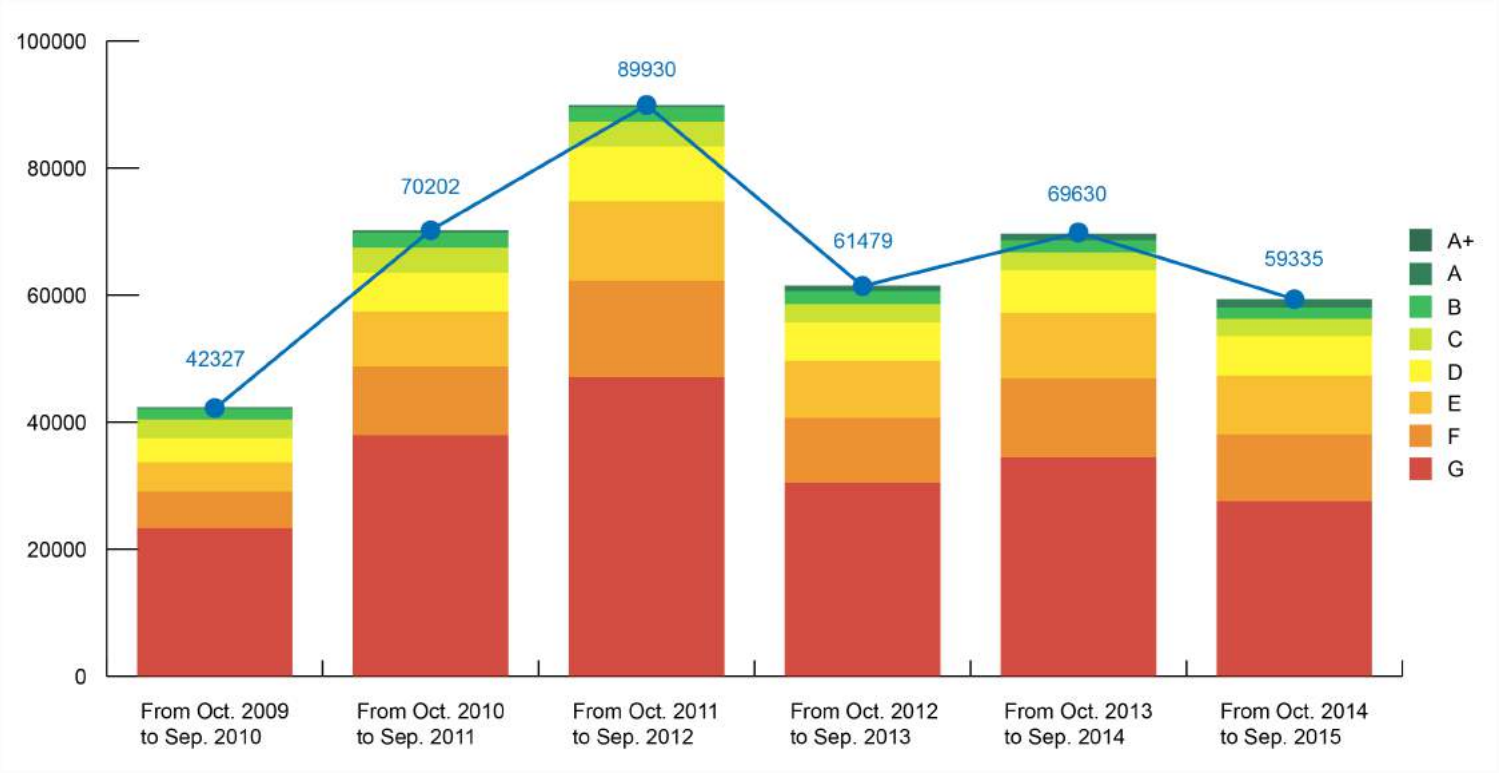
The weighted value of EPCs with dwellings in the Metropolitan City of Milan



Data source: CENED database, as of September 2015. Elaborated by the author.

Evolution of deposit of Energy Performance Certificate in CENED database

- The EPC became mandatory for buying and selling individual units in July 2009.
- The EPC became mandatory for leasing in July 2010.
- The EPC became mandatory for commercial advertisements in February 2012.

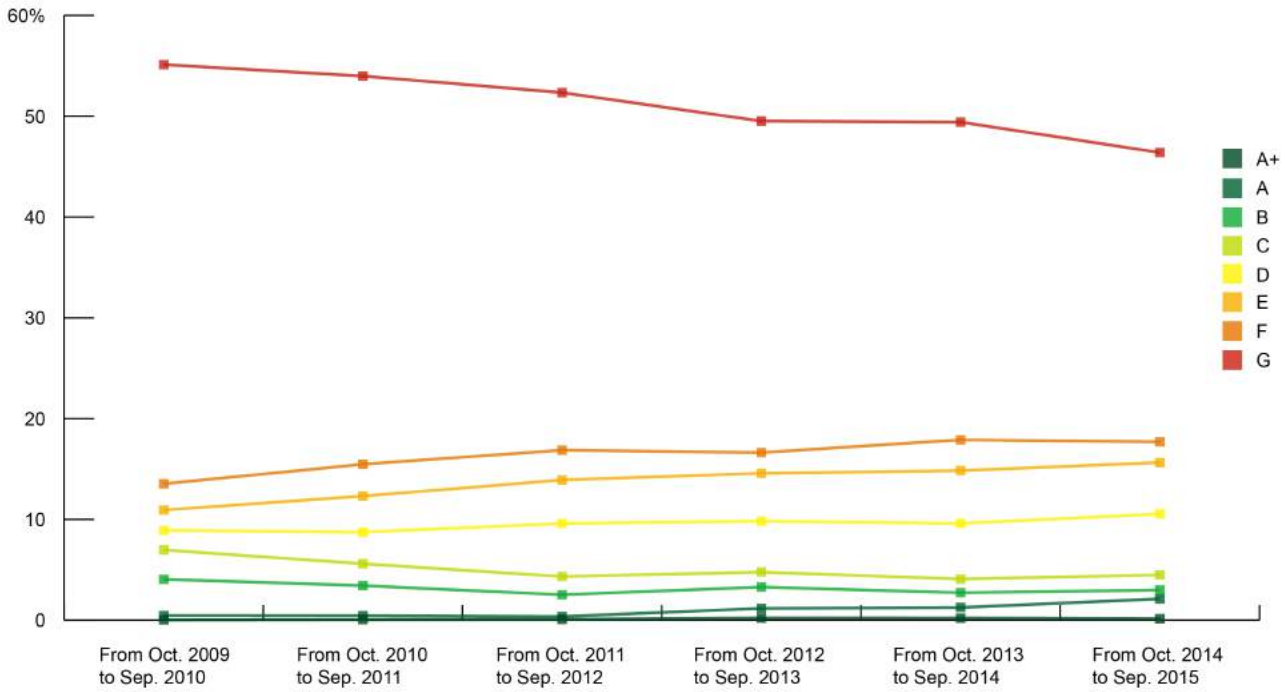


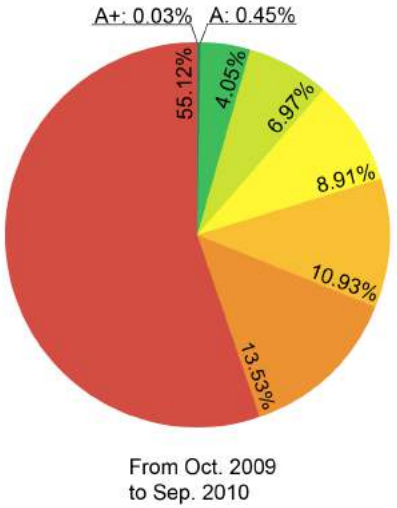
Data source: CENED database, as of September 2015. Elaborated by the author.

Trend of energy classes from Oct. 2009 to Sep. 2015

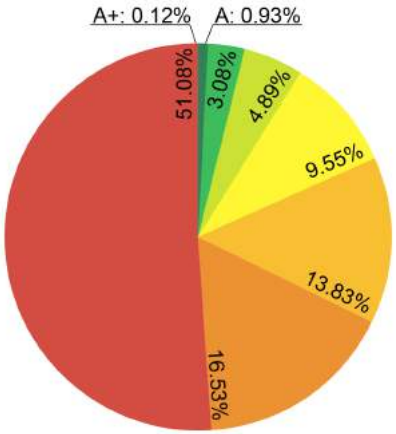
- The proportion of G class is decreasing over time.
- The proportions of A+ class and A class are increasing but slightly.

The charts were based on the existing EPCs in the Metropolitan City of Milan.





From Oct. 2009 to Sep. 2010



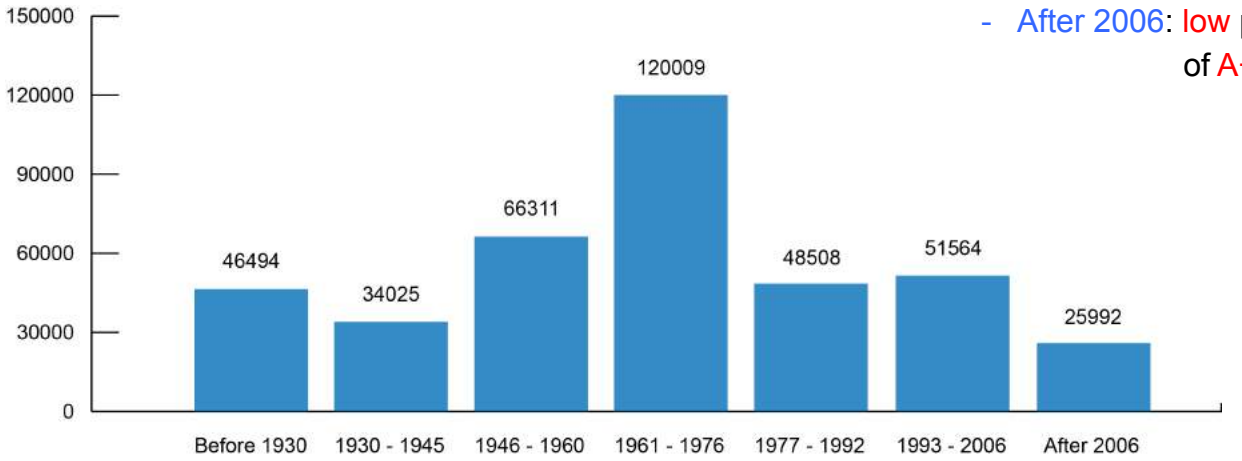
From Oct. 2009 to Sep. 2015

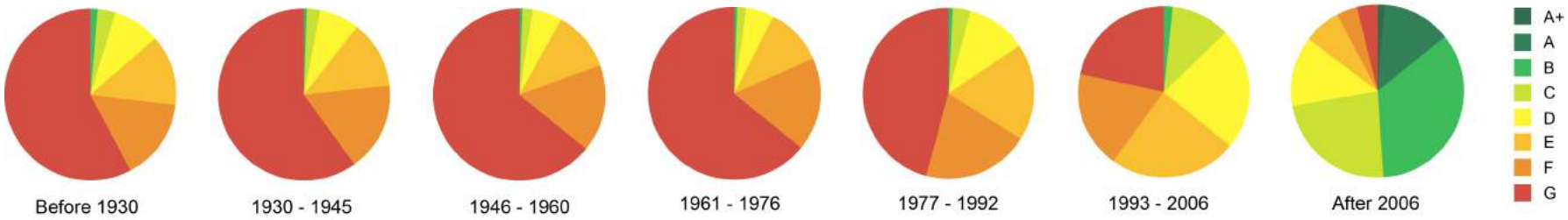
Data source: CENED database, as of September 2015. Elaborated by the author.

Periods of construction and energy class

The statistics was based on the existing EPCs in the Metropolitan City of Milan.

- Before 1976: relatively high proportion of G class;
- During 1961-1976: highest proportion of G class;
- After 2006: low proportion of G class, and high proportion of A+ and A class .



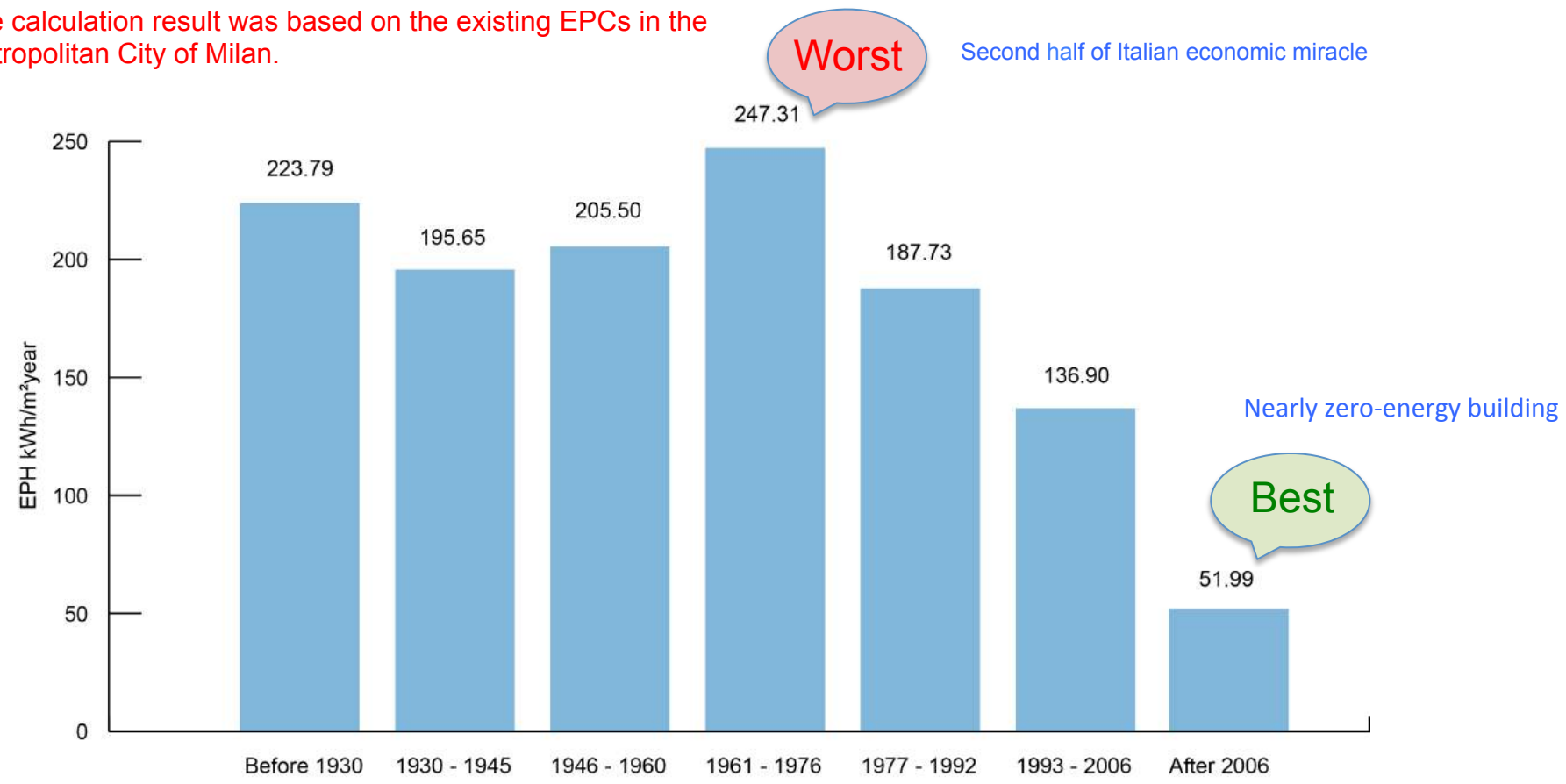


Data source: CENED database, as of September 2015. Elaborated by the author.

Periods of construction and energy efficiency

EP_H: primary energy demand for unit indoor space heating in a year (kWh/m²year).

The calculation result was based on the existing EPCs in the Metropolitan City of Milan.



Data source: CENED database, as of September 2015. Elaborated by the author.

Method: weighted average method

The calculation was based on the existing EPCs in the Metropolitan City of Milan, as of Sep. 2015.

$$EPH_a = \frac{s_1 eph_1 + s_2 eph_2 + \ldots + s_n eph_n}{s_1 + s_2 + \ldots + s_n} = \frac{\sum_{i=1}^{n} s_i eph_i}{\sum_{i=1}^{n} s_i}$$

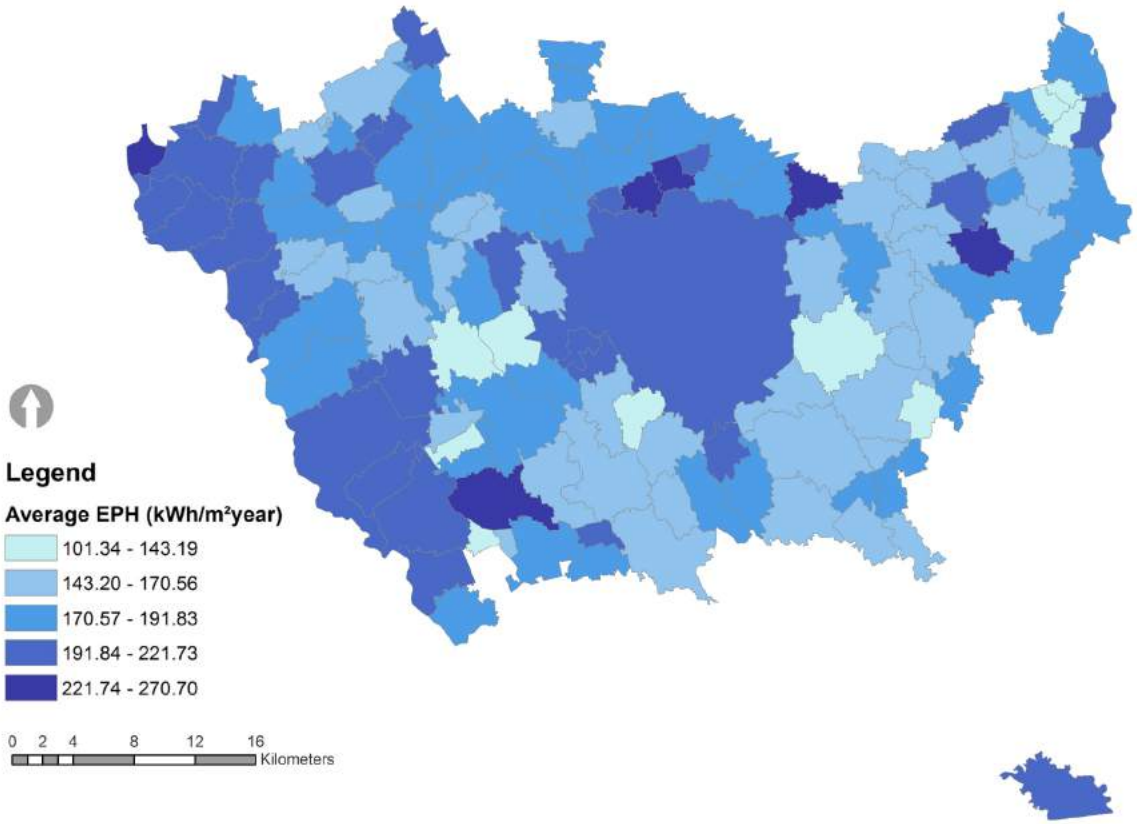
Where s_i is the net area of the dwelling and eph_i is the corresponding EP_H. So the numerator represents the total primary energy demand for heating for all dwelling that have EPC in one year in a certain municipality, and the denominator represents the sum of the net area of these dwellings.

OID_	COMUNE	Sum_SUPERF	Sum_TOT_EP	A_EPH
0	ABBIATEGRASSO	405095.4466	80769597.04	199.38
1	ALBAIRATE	57901.4077	11596462.84	200.28
2	ARCONATE	67205.446	12455411.62	185.33
3	ARESE	369756.2078	63300248.23	171.19
4	ARLUNO	163782.4837	29152623.69	178
5	ASSAGO	149748.831	17700078.89	118.2
6	BARANZATE	118452.4996	25933740.83	218.94
7	BAREGGIO	183122.1909	33537689.95	183.14
8	BASIANO	50135.562	8938851.79	178.29
9	BASIGLIO	101199.558	15351909.9	151.7
10	BELLINZAGO LOMBARDO	43762.1571	8157847.93	186.41
11	BERNATE TICINO	32262.48	6370066.46	197.45
12	BESATE	20262.22	4118926.41	203.28
13	BINASCO	108209.8924	22555295.79	208.44
14	BOFFALORA SOPRA TICINO	43536.3211	9216928.25	211.71
15	BOLLATE	428067.2846	77448879.58	180.93

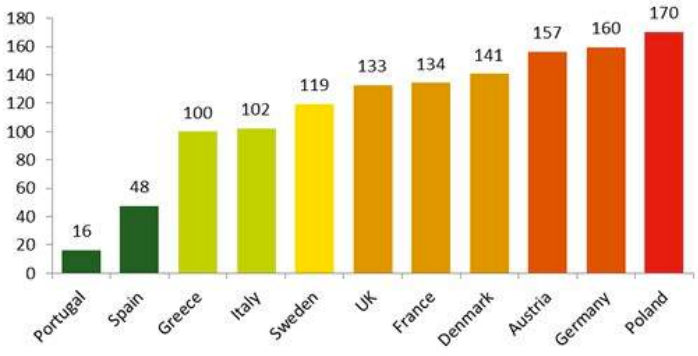
Data extracted from CENED database and calculated in GIS.

The indicator of average energy efficiency in the residential sector

Average EP_H of the Metropolitan City of Milan: 197.09 kWh/m^2year.
Average EP_H of the City of Milan: 212.43 kWh/m^2year.
High energy efficiency: Assago, Cusago and Tribiano.
Low energy efficiency: Cologno Monzese, Melzo and Rosate.



Data source: CENED database, as of September 2015. Elaborated by the author.

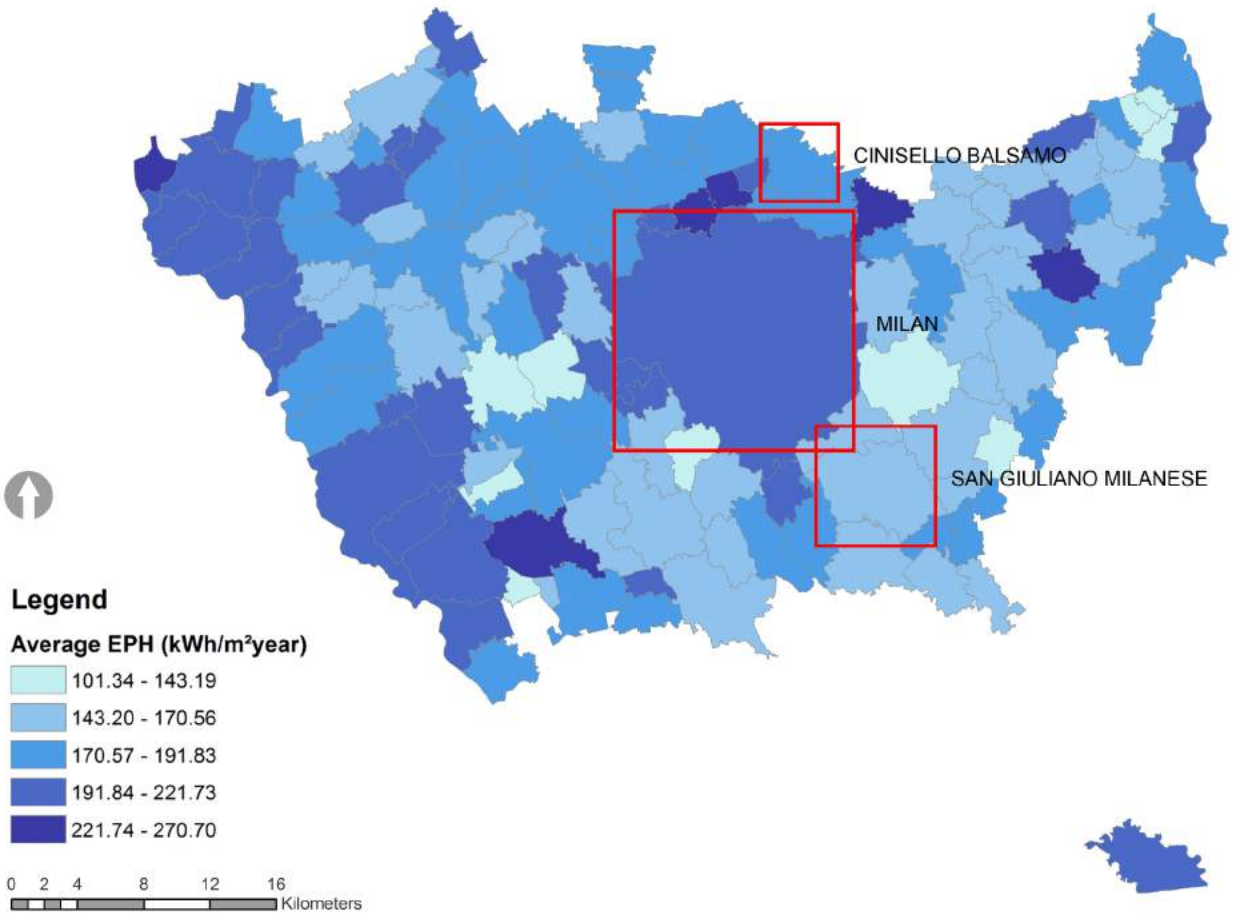


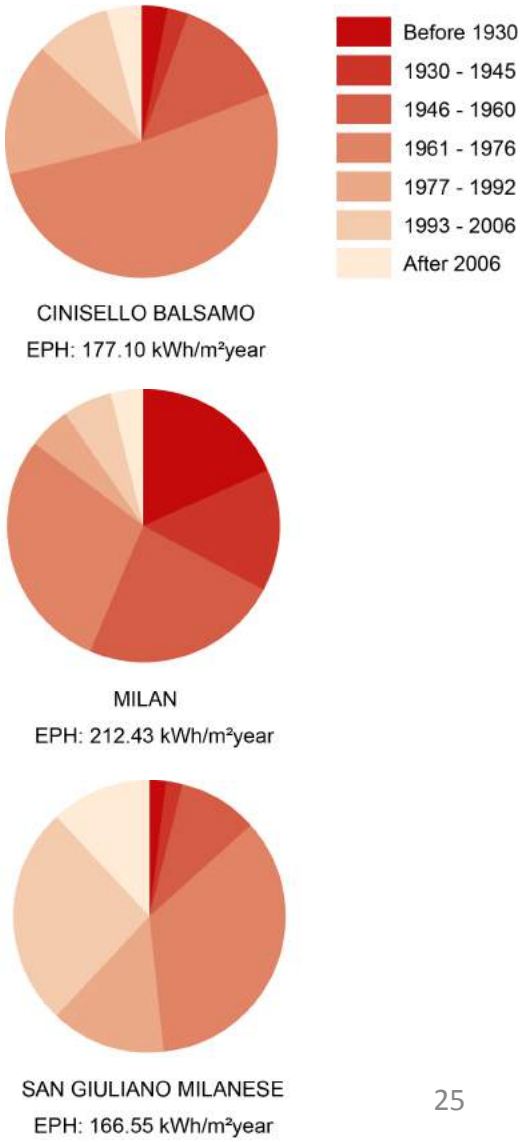
Primary energy demand for heating per unit of floor area (kWh/m^2year). Source: Odyssee

Lakes, rivers and canals in the Lombardy region.

Analysis of the energy efficiency and periods of construction

Different energy efficiencies because of the different composition of residential buildings constructed in different periods.

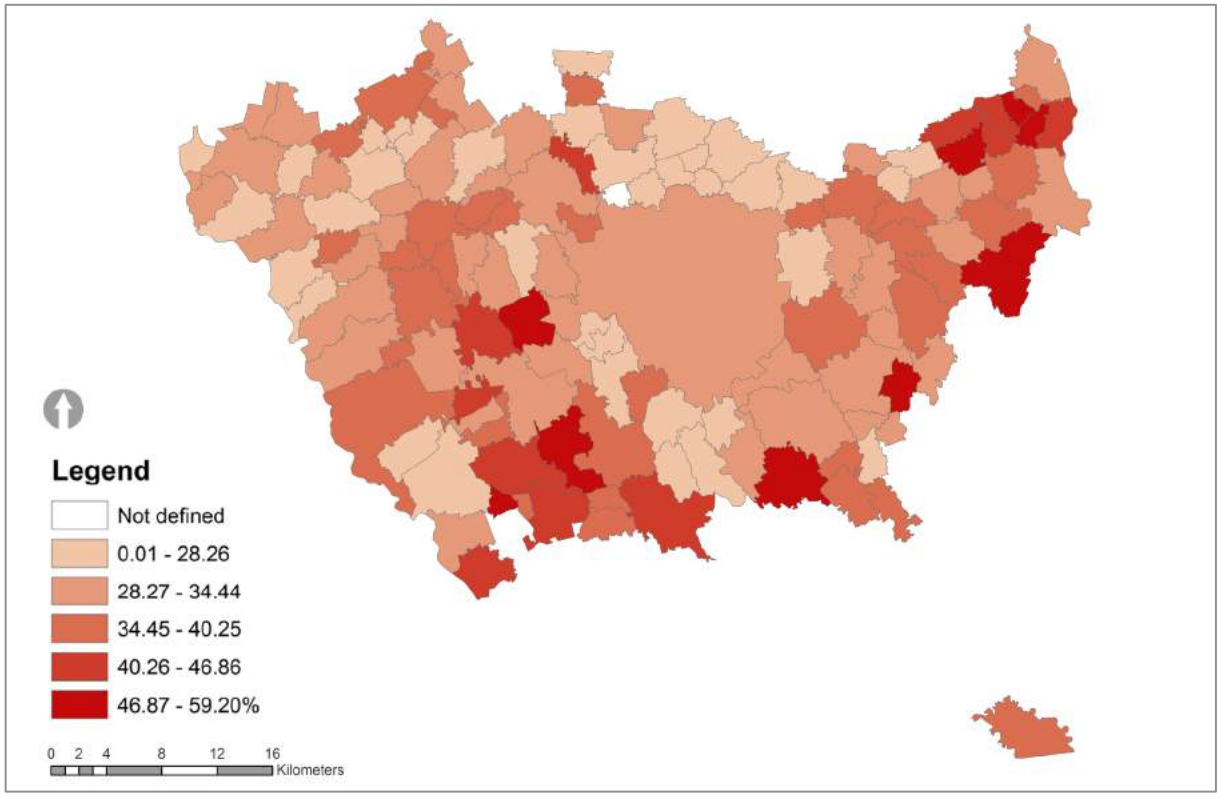




The committed cities for reducing energy consumption in the residential sector

Three criteria were considered:

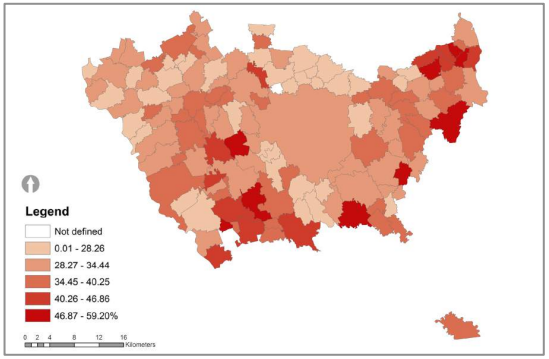
1. EPC and dwelling ratio, as of September 2015 (CENED)



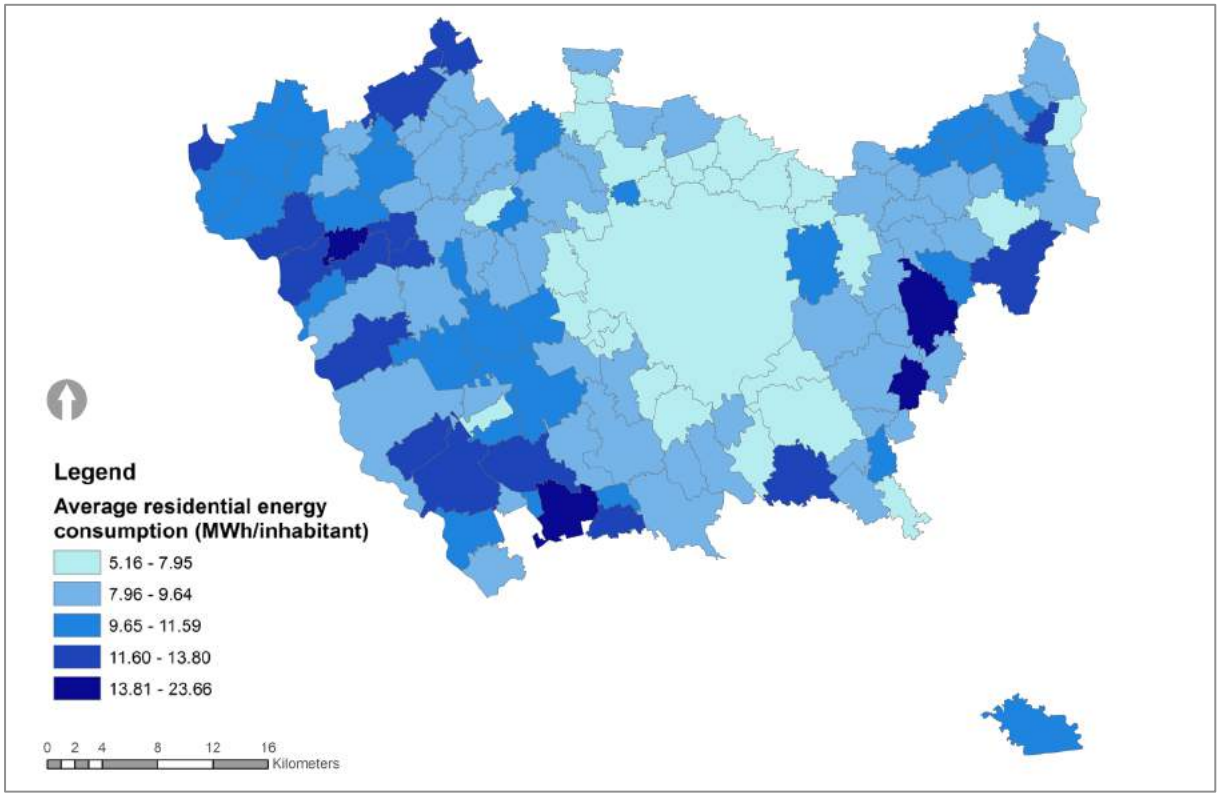
Energy efficiency and residential sector – Urban level

The committed cities for reducing energy consumption in the residential sector

Three criteria were considered:
1. EPC and dwelling ratio, as of September 2015 (CENED)



2. Average residential energy consumption in 2010 (SIRENA20)

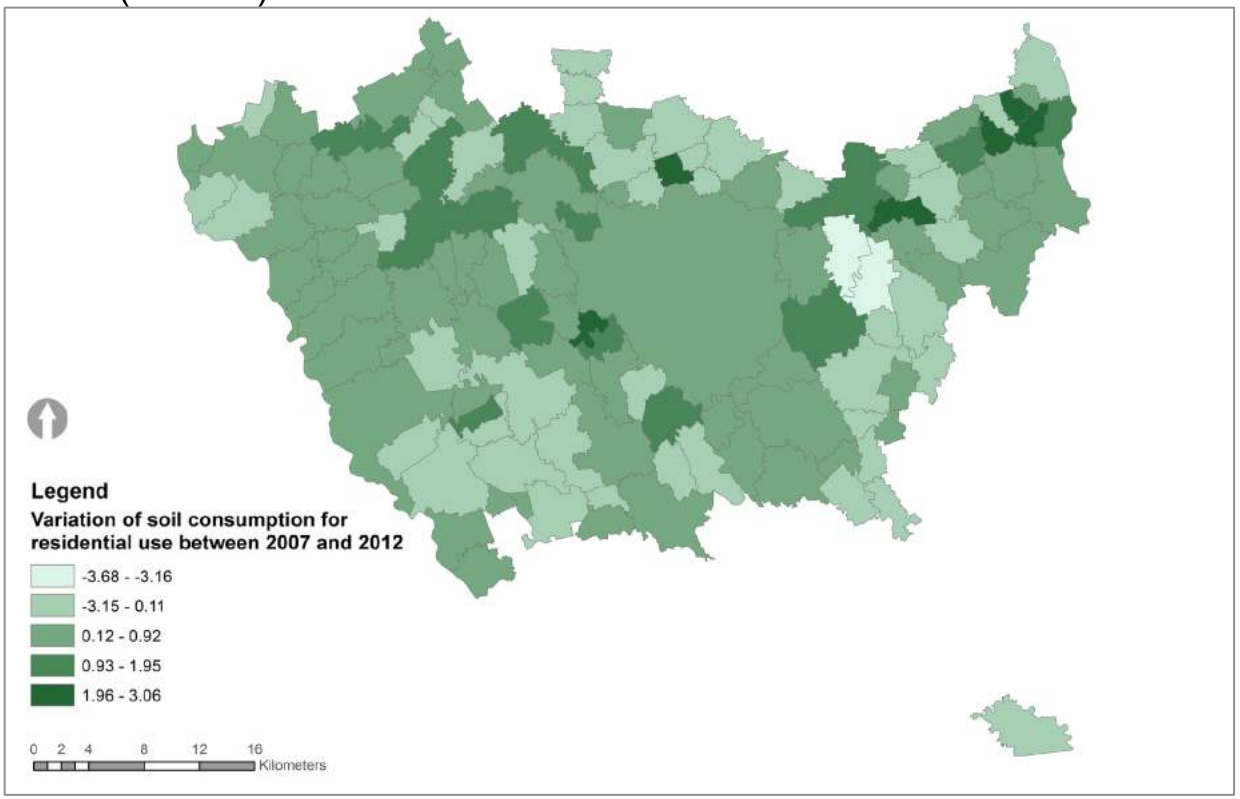


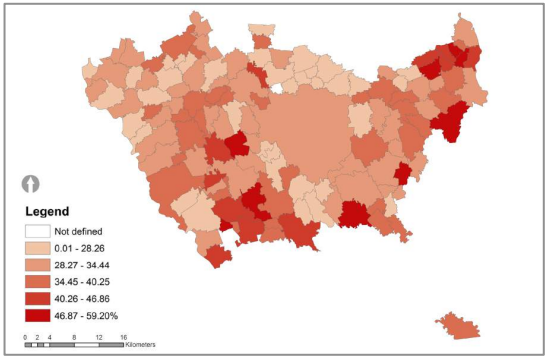
The committed cities for reducing energy consumption in the residential sector

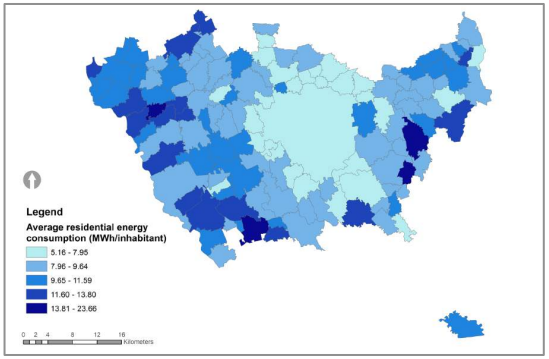
Three criteria were considered:

1. EPC and dwelling ratio, as of September 2015 (CENED)
2. Average residential energy consumption in 2010 (SIRENA20)

3. Variation ratio of soil consumption for residential use between 2007 and 2012 (DUSAF)







Overlapping three indicators

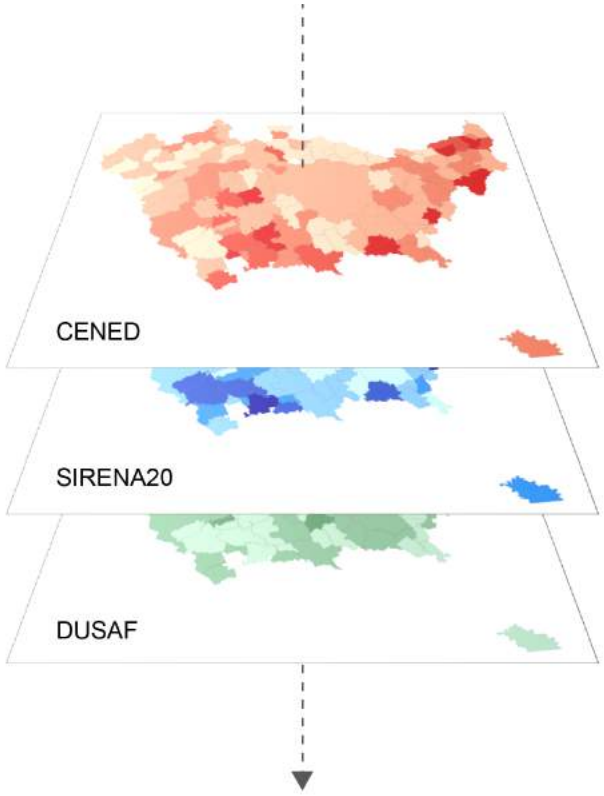
The Min-Max normalization method:

$$A' = \left(\frac{A - \min value\ of\ A}{\max value\ of\ A - \min value\ of\ A} \right) * (D - C) + C$$

where, A' contains Min-Max Normalized data one, A is the range of original data, [C, D] is the pre- defined boundary. In this case, D and C are respectively equal to 1 and 0 .

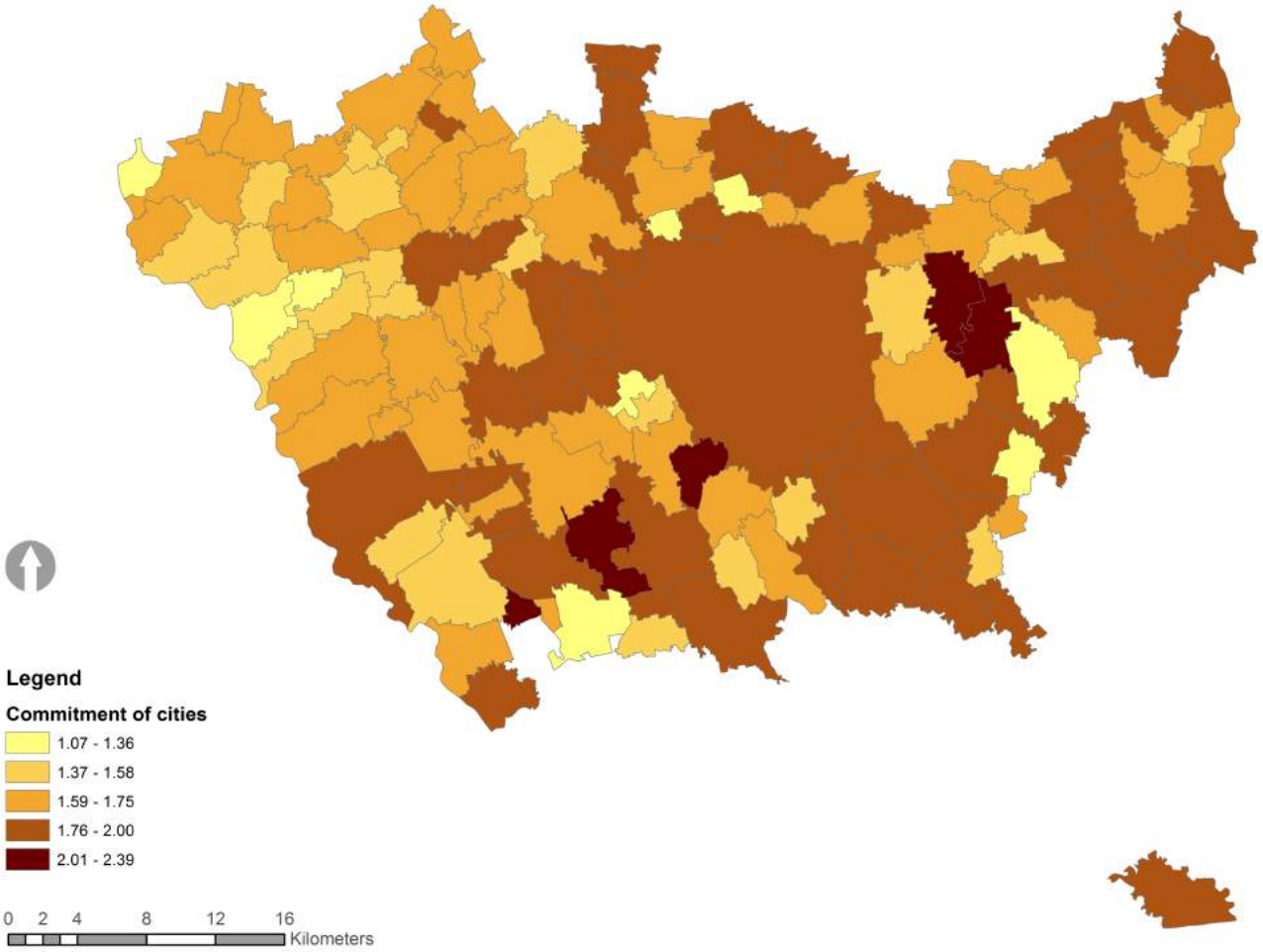
Name of the indicator	Range of the score
EPCs and dwelling ration, as of September 2015	From 0 to 1
Average residential energy consumption in 2010	From 0 to 1
Variation ratio of soil consumption for residential use between 2007 and 2012	From 0 to 1
Committed cities	From 0 to 3

Overlapping of three indicators

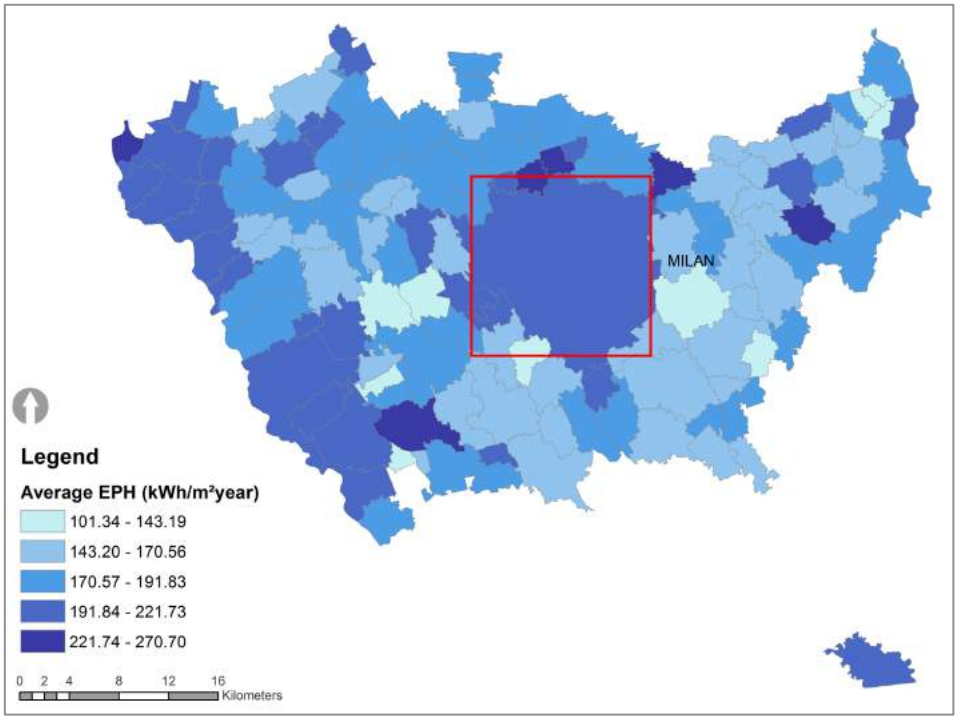


The commitment of cities

The most committed cities (dark brown), which took most actions for reducing energy consumption and improving energy efficiency in the residential sector are: Assago, Bubbiano, Noviglio, Pioltello and Rodano.



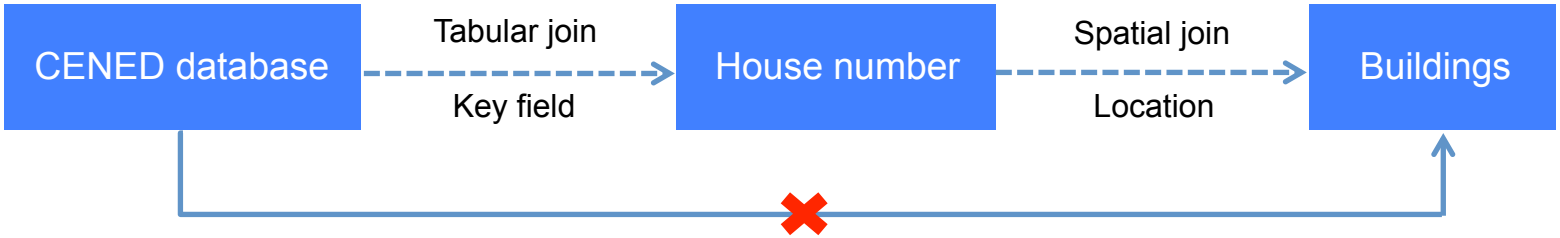
Study area: historical center of Milan



Definition of the historical center of the City of Milan. Elaborated by the author.

* This section was realized during the advanced course (corso di perfezionamento in sistemi informativi e governo integrato del territorio) of prof. Paolillo.

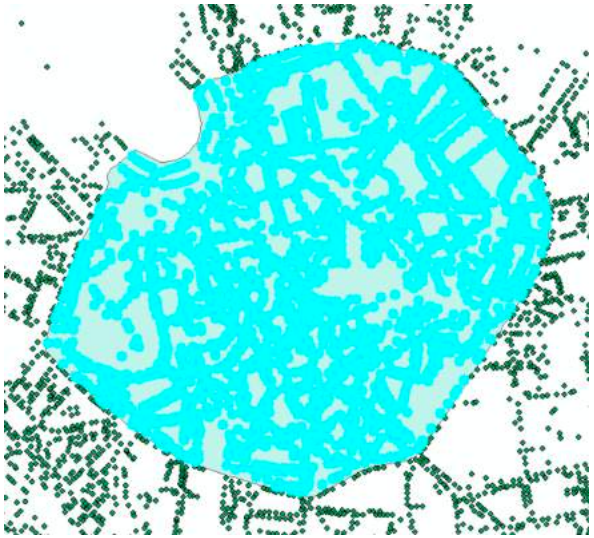
Method



- A residential building may contains Energy performance certificate from zero to the number of dwellings it has (max).
- Among which the lowest energy class was considered as the energy class of the entire building for not overestimating its energy performance.

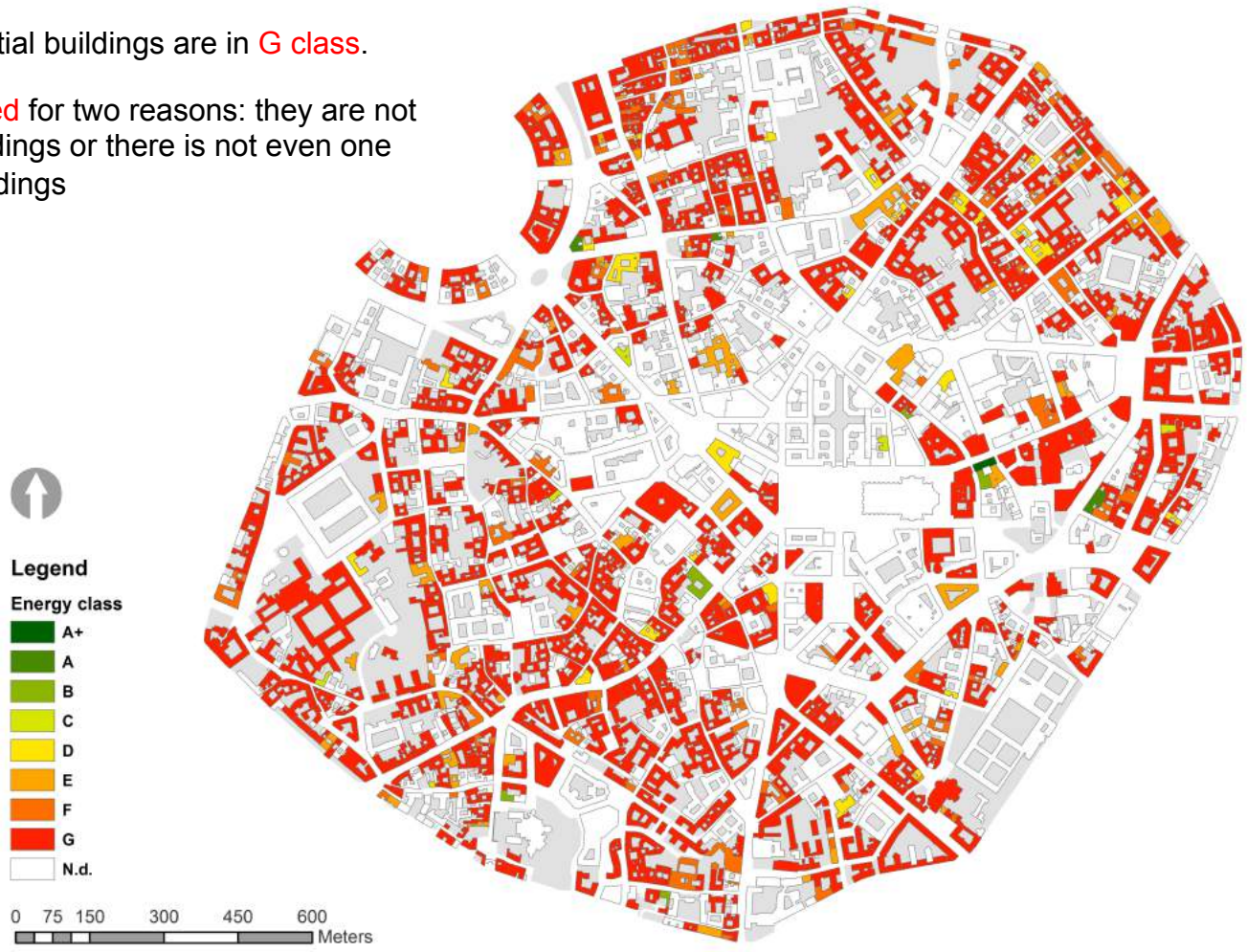
Geospatial data: buildings

Geospatial data: house number



Energy class map of the historical center of Milan, as of September 2015

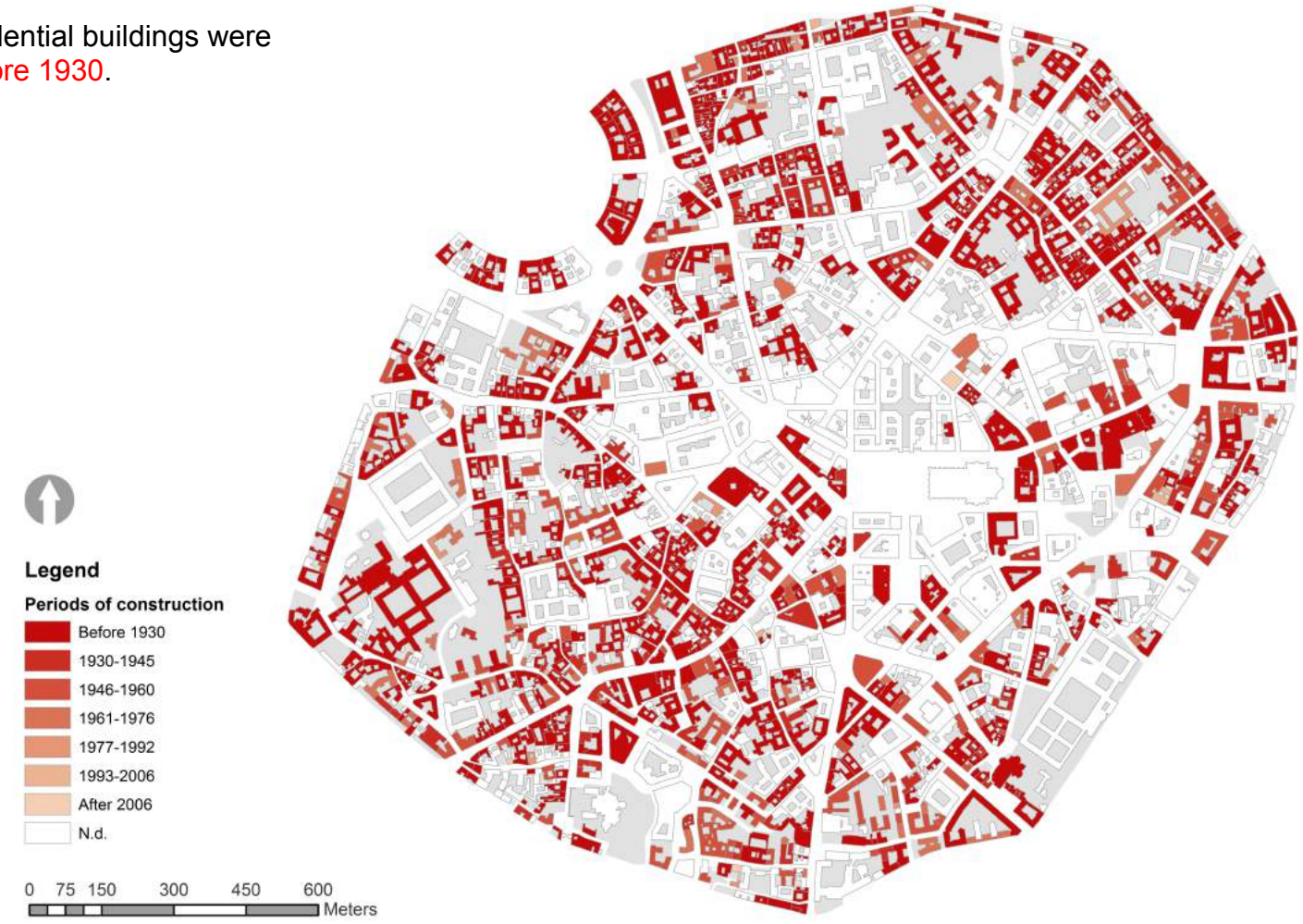
- Most of the residential buildings are in G class.
- Buildings not defined for two reasons: they are not residential use buildings or there is not even one EPC inside the buildings



Data source: CENED database. Elaborated by the author.

Periods of construction of residential buildings, as of September 2015

Most of the residential buildings were constructed before 1930.



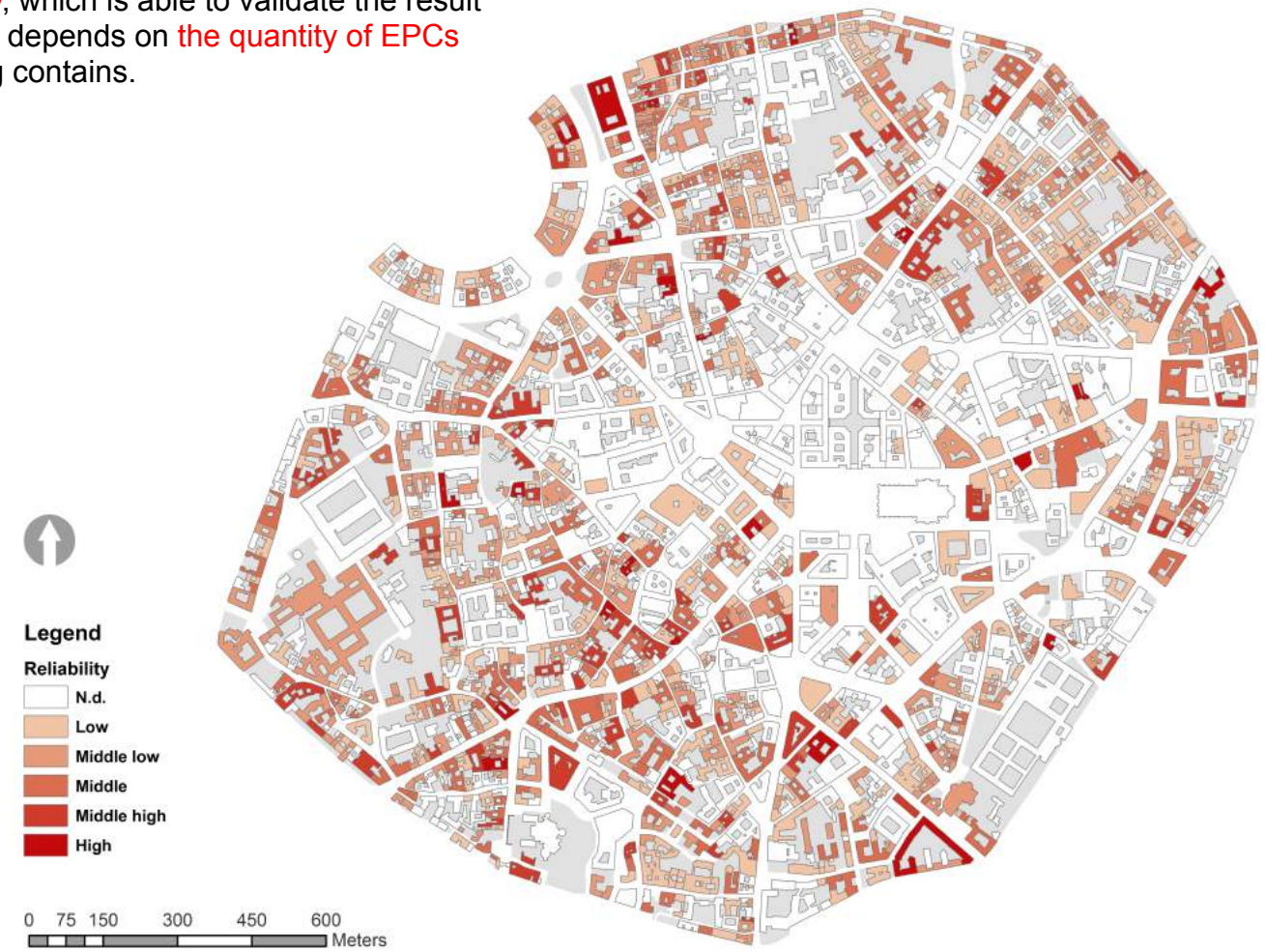
Data source: CENED database. Elaborated by the author.

Representation of residential buildings' energy classes in 3D for easy communication

Data source: CENED database. Elaborated by the author.

Validation of the result

The indicator of reliability, which is able to validate the result of the energy class map, depends on the quantity of EPCs that a residential building contains.

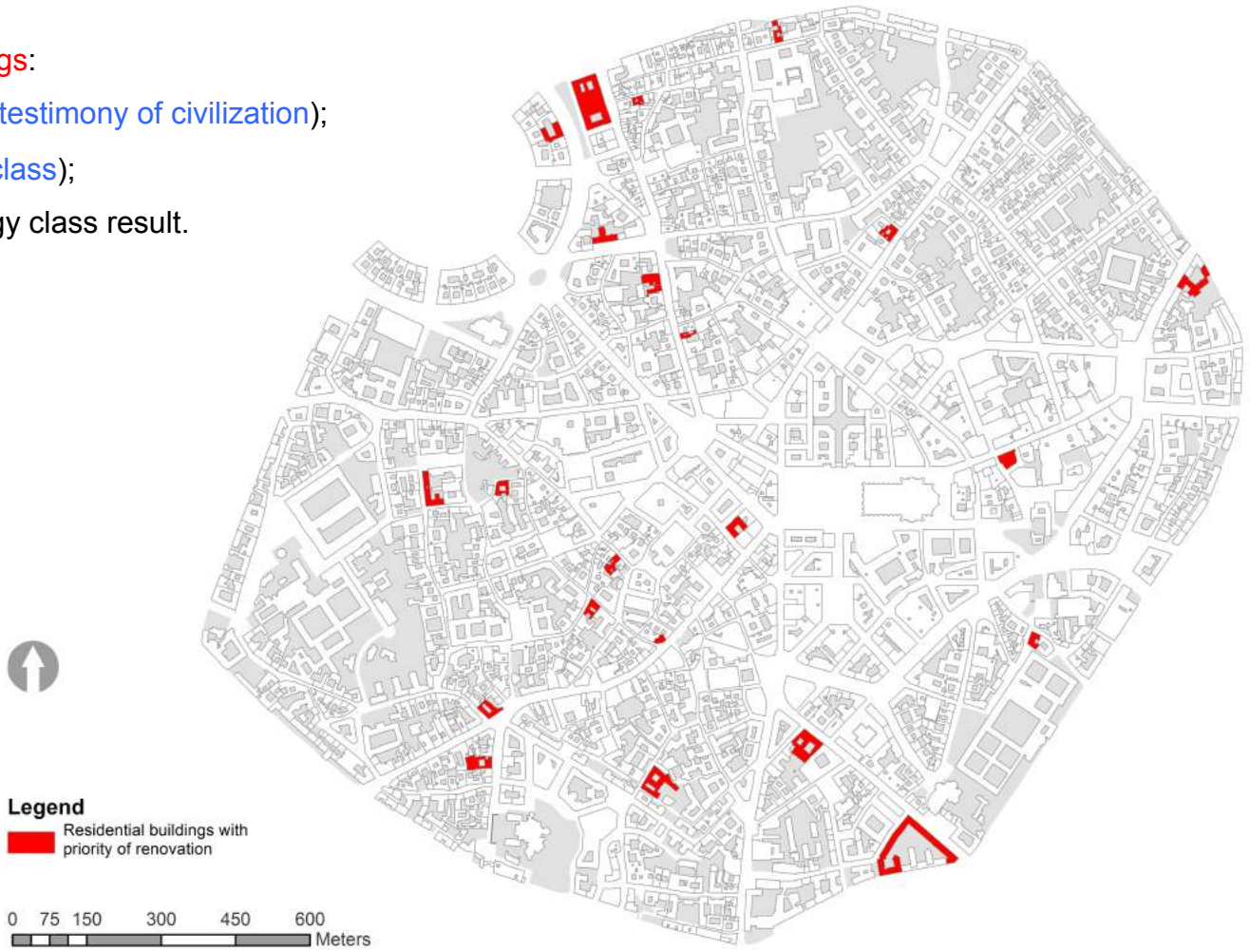


Data source: CENED database. Elaborated by the author.

Residential buildings with priority of renovation in terms of energy efficiency

Criteria of selecting the buildings:

- Constructed before 1930 (testimony of civilization);
- Low energy efficiency (G class);
- High reliability of the energy class result.



Data source: CENED database. Elaborated by the author.

Limitations of the research

1. Regional and provincial level: inaccurate energy consumption data (estimated) and simplified assumptions.
2. Urban level: incomplete CENED database and errors contained in the data.
3. Building level: incomplete CENED database and unknown number of dwellings contained in each residential buildings.

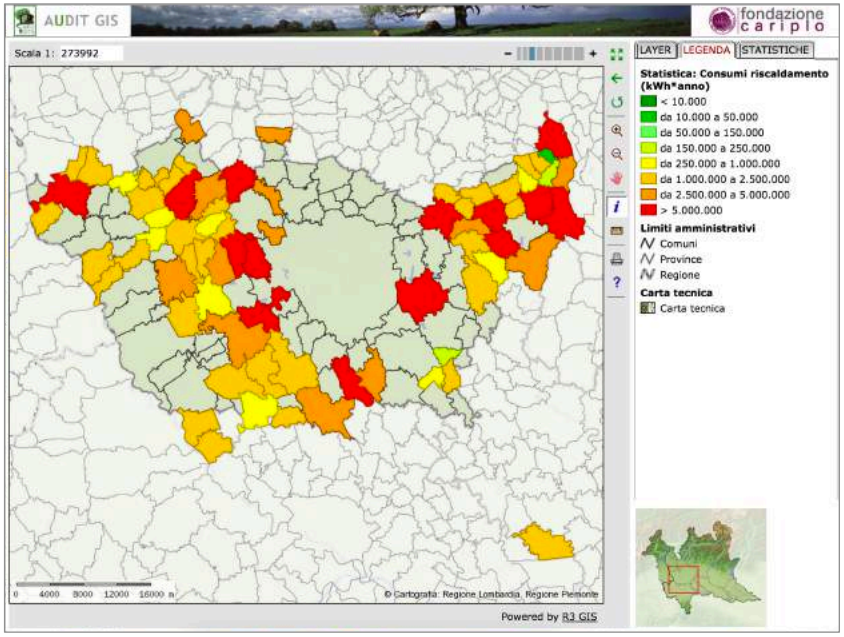
Recommendations

1. Prioritize and accelerate the completion of energy database regarding to the residential building stock, such as CENED, on a large territorial scale.
2. Advocate and encourage the use of renewable energy sources as an alternative energy in the residential sector for a more sustainable development.
3. Mitigate or contain soil consumption for residential use is a potent means to reduce residential sector's energy consumption.
4. Involve varied professionals in the process of making energy plans and strategies for reducing energy demand and improving energy efficiency in the residential sector.
5. Strengthen a timely and effective communication between public administration and citizens to change citizens' energy awareness through a kind of interactive map online.

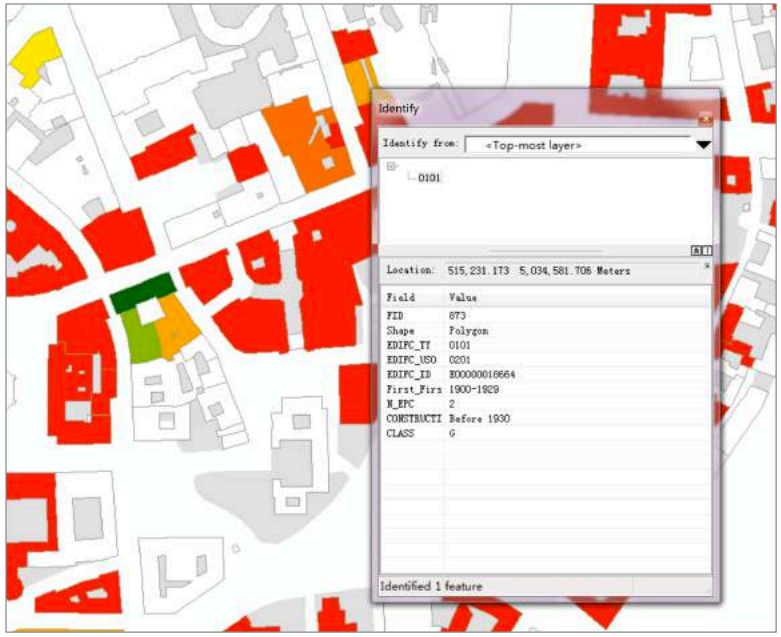
Future possible applications

1. Identify the potential energy saving in terms of energy efficiency in the residential sector.

2. Provide the service of energy pre-certification of residential buildings.



Source: Fondazione Cariplo.



Source: GIS interface.

Thank you !