Energy Challenges and Environmental Sustainability

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Exercise One: SDGs and Energy Trilemma Indexes of SPAIN

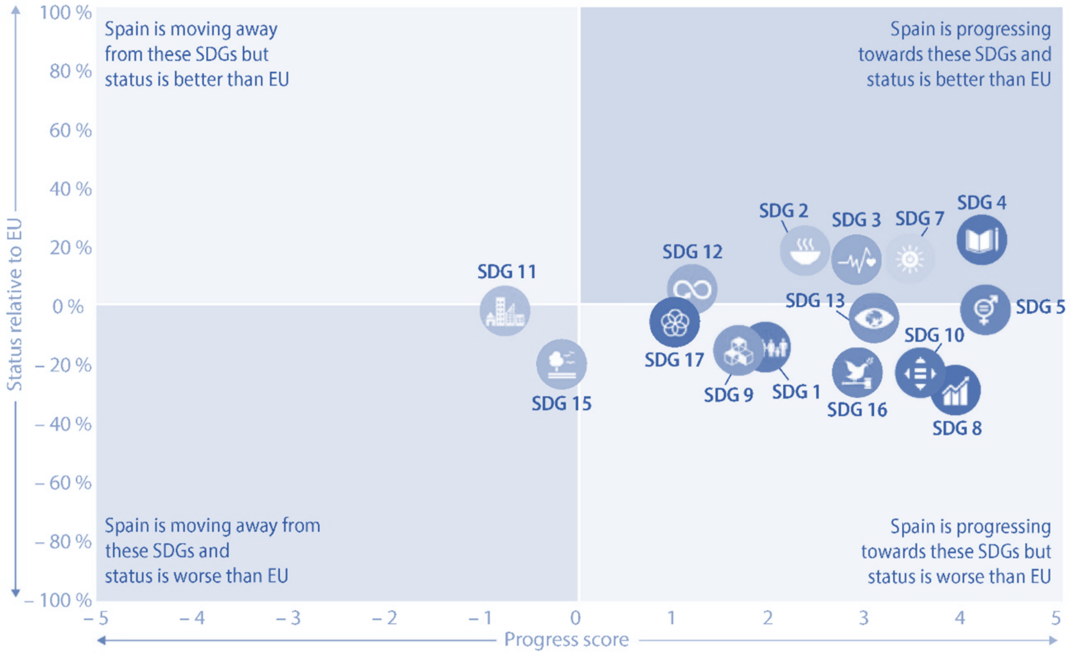
Purpose:

To describe and analyze Spain's Sustainable Development Goals and Energy Trilemma Indexes. Compare these data with Italy's information, and create a SWOT chart.

Sustainable Development Goals Analysis

COUNTRY RANKING

SPAIN	ITALY
16/163	25/163



SPAIN

ITALY

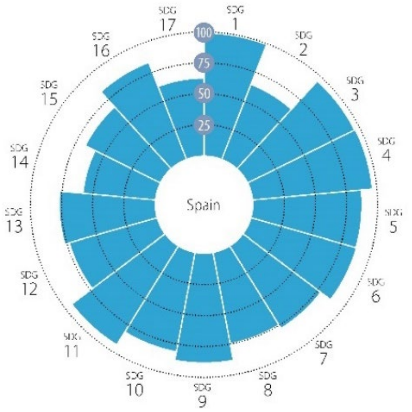
7. Affordable and Clean Energy

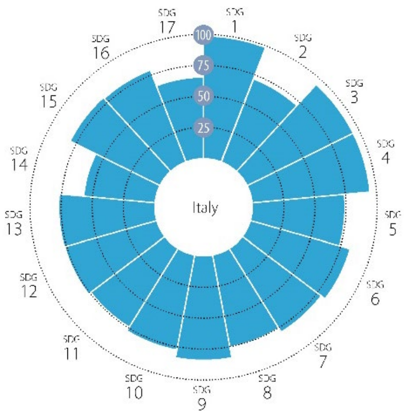
11. Sustainable and Cities and Communities

12. Responsible Consumption and Production

13. Climate Action

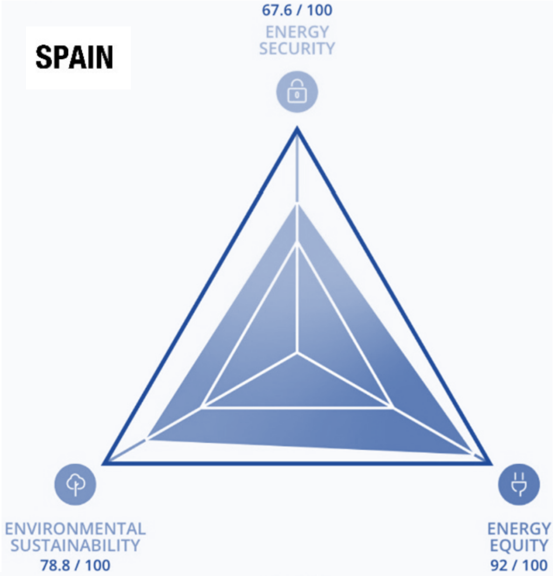
AVERAGE PERFORMANCE BY SDG

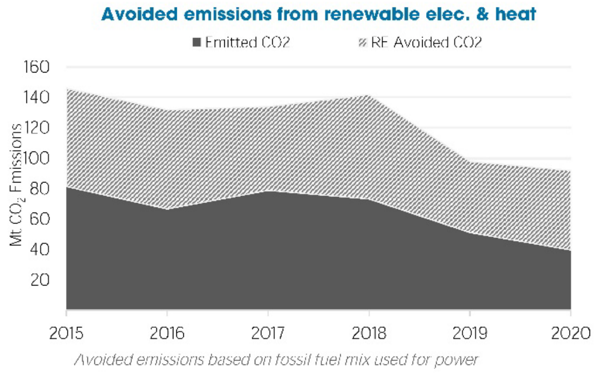


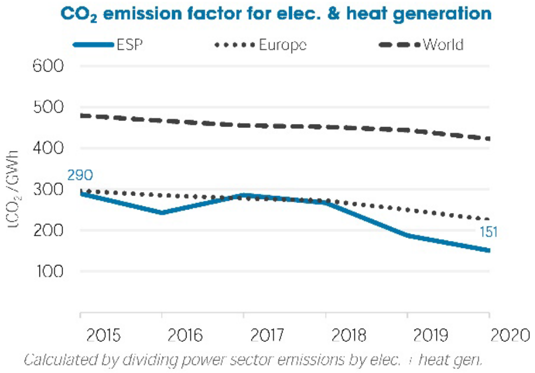


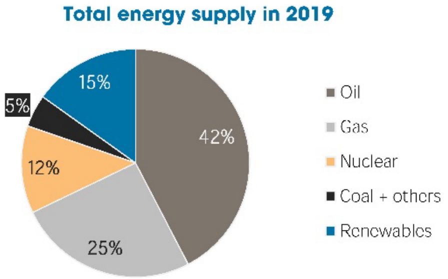
COUNTRY SCORE

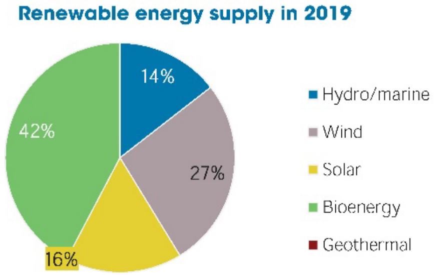
Energy Trilemma Index Analysis

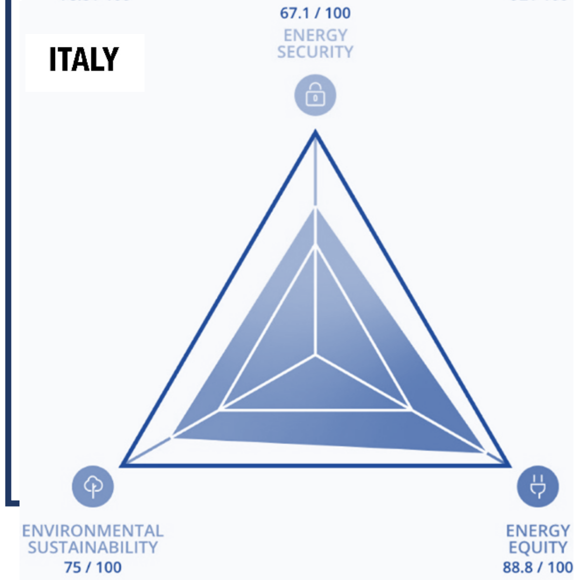


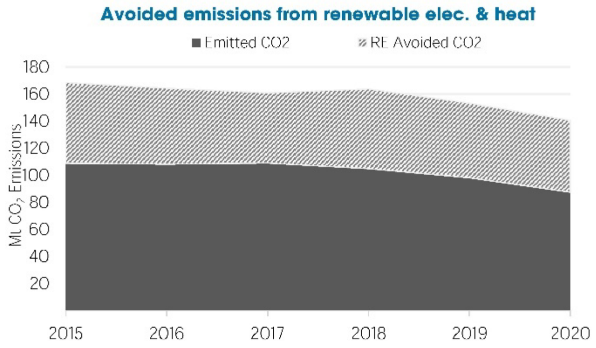


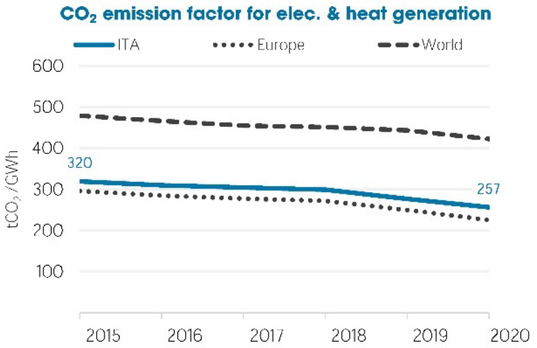


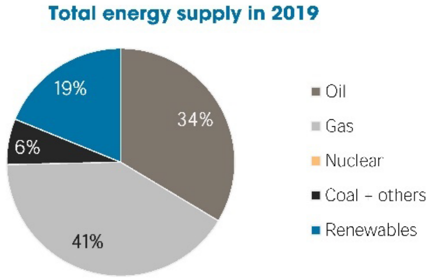


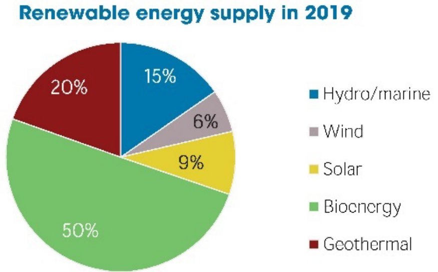












Conclusion

- Both countries show resilience against similar challenges and improved accordingly in SDGs and Energy Trilemma.
- Both have demonstrated acceptable performance in almost all SDGs and set policies at social and national levels to improve them.

	Spain	Italy
Strengths	*High Performance in SDGs 1, 3, and 4. *Desirable Status above EU average in SDGs 2, 3, and 7. *Low CO_2 Emissions (Lower than EU) *Well-Established Gas Infrastructures *Building Decarbonized Economy	*High Performance in SDGs 1, 3, and 4. *Desirable Status above EU average in SDGs 3, 7, and 12. *High Potential in Biomass *Energy Efficiency
Weaknesses	*Moving away from SDG 15 *Historical high level in Energy Prices *Inflation at 10.2%	*Moving away from SDG 10 *Far below EU average in SDGs 8 *Decentralized Energy Policies due to Regionalization *High increase in Energy Prices *No Improvement in Energy Sectors since 2018
Opportunities	*Hydro Carbons Strategic Stocks Control System *Diversity of Energy Suppliers	*High potential in Solar, Hydro/Marine, and Biomass.
Threats	*Russia – Ukraine War *Post-Covid Economy Crisis	*Russia – Ukraine War *Post-Covid Economy Crisis *Reliance on one country's source of energy

Exercise Two: Solar Radiation and Photovoltaic Potential

Purpose:

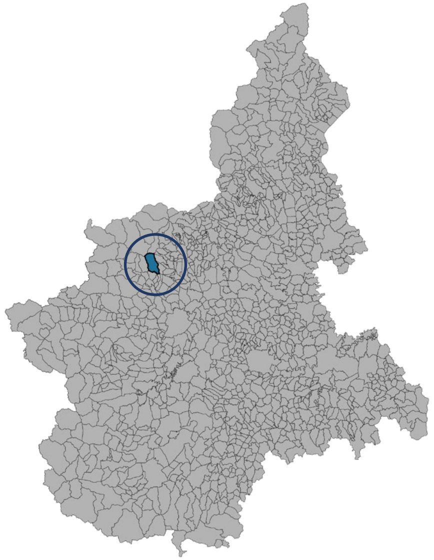
Calculation of Photovoltaic Electricity Production Potential in Corio Municipality. And its sufficiency and efficiency for Corio.

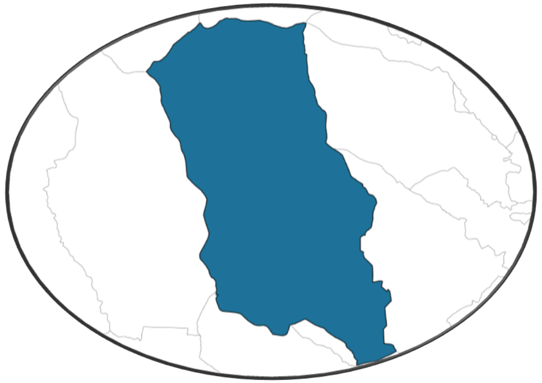
Introduction

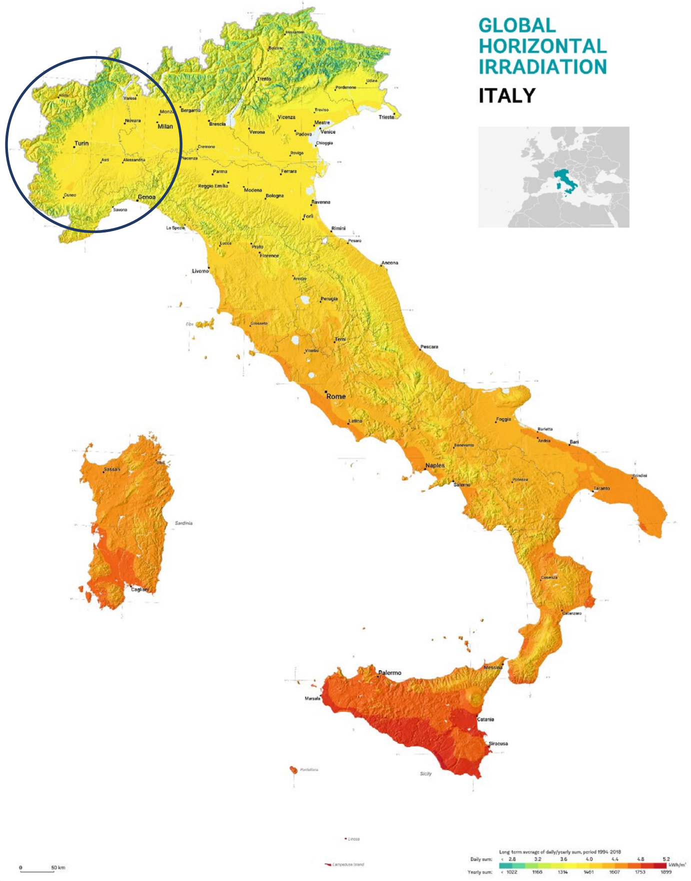
A **photovoltaic system** employs solar modules, each comprising a number of solar cells, which generate electrical power.

Solar Radiation is affected by atmospheric conditions such as optical thickness and cloud cover; topographical characteristics such as latitude, slope, aspect, and shadow cast; ecological processes such as snow melting, and evapotranspiration; and human activities. In most cases, insolation is the result of the interactions between all these factors (Duffie & Beckman, 1991; Hofierka & Suri, 2002).

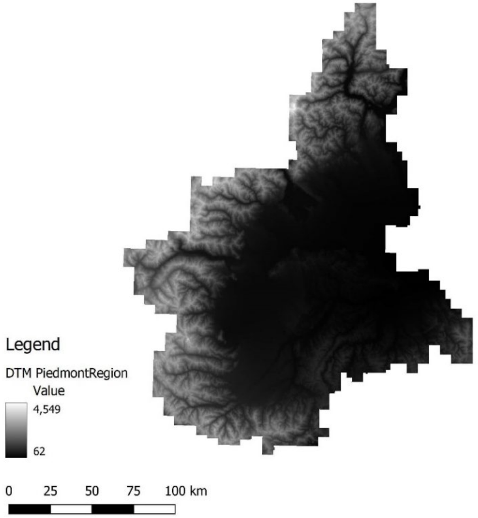
Corio is a commune (municipality) in the Metropolitan City of Turin in the Italian region of Piedmont, located about 30 kilometers northwest of Turin. The population of this city has been reported **3,260** in 2017.

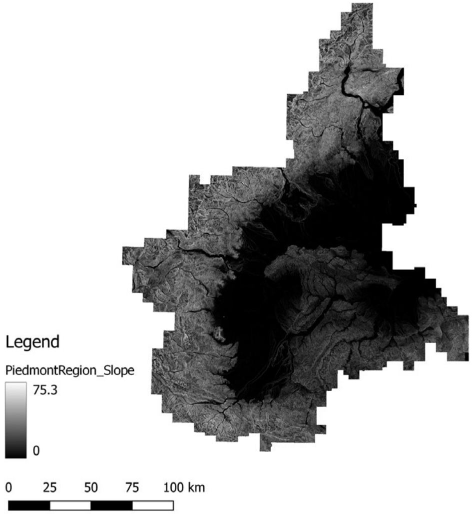


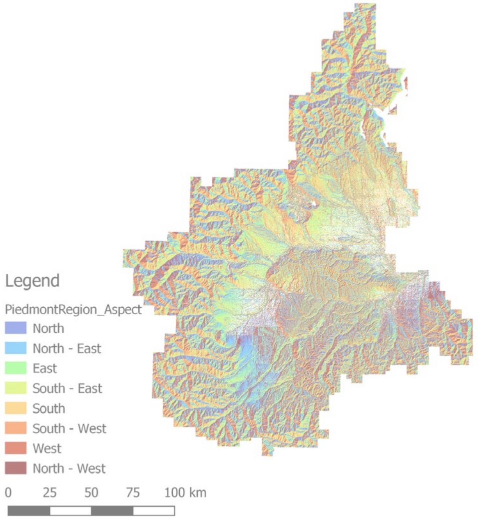




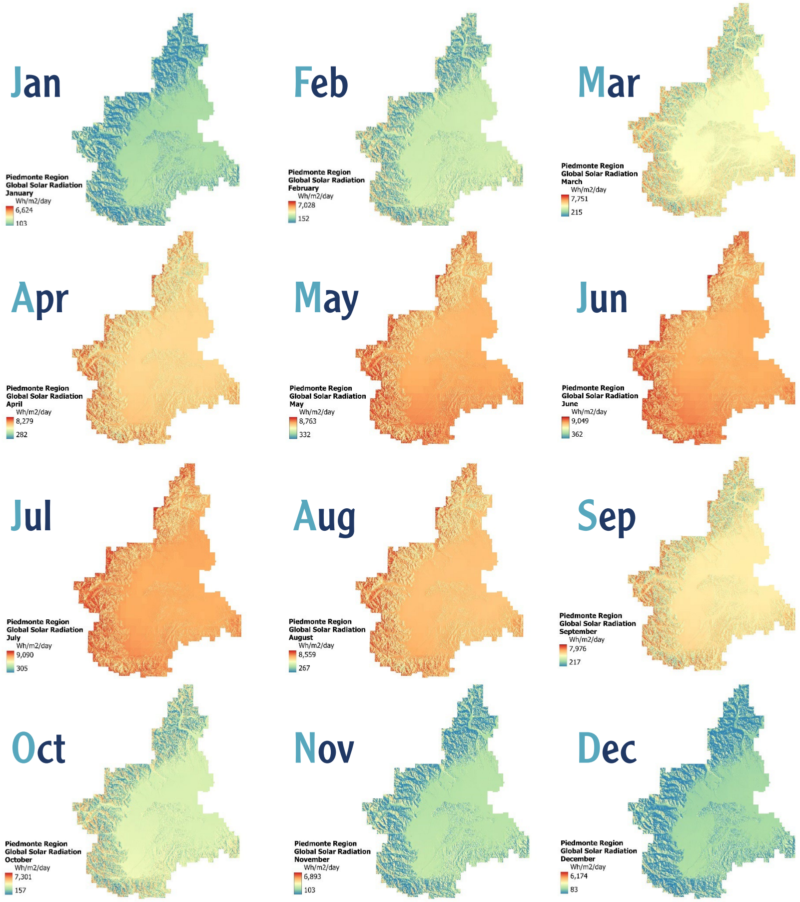
1. DTM Translation and Slope and Aspect Raster Creation





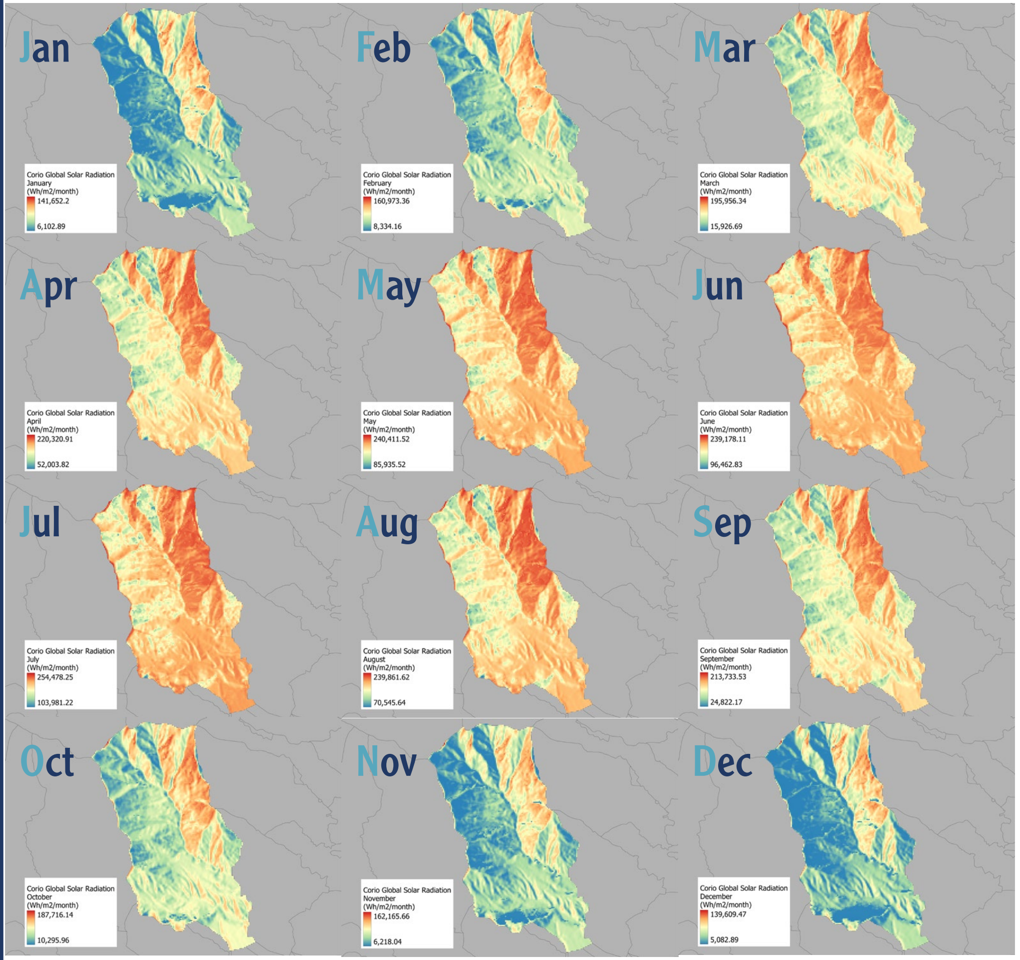


2. Global Solar Radiation on The Average Day

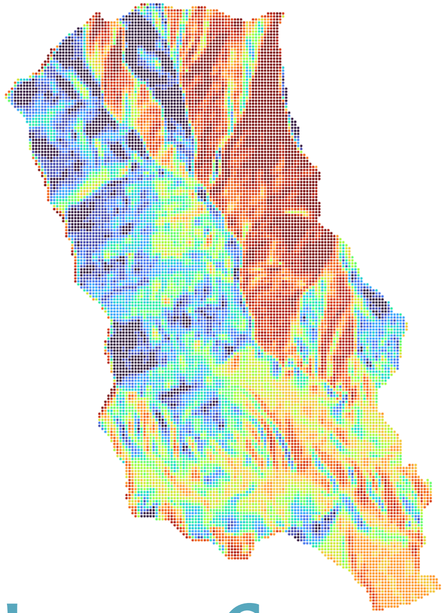


3. Global Solar Radiation Conversion to Monthly Data

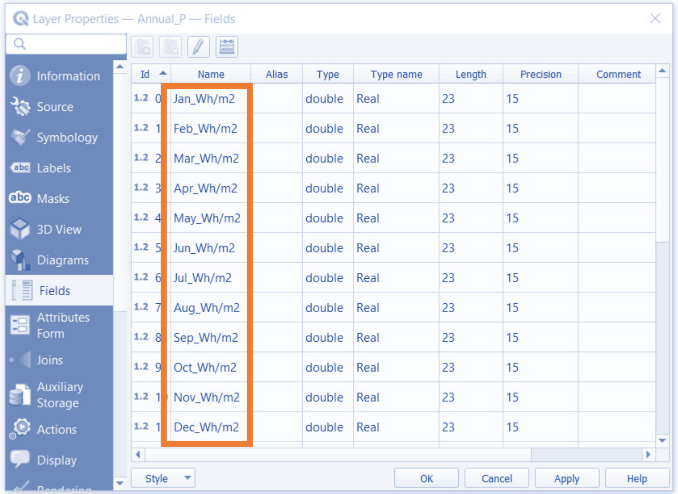
4. Municipality Case Study Extraction



5. Raster to Point Conversion



6. Unitary Shapefile Creation Containing 12 Month Data



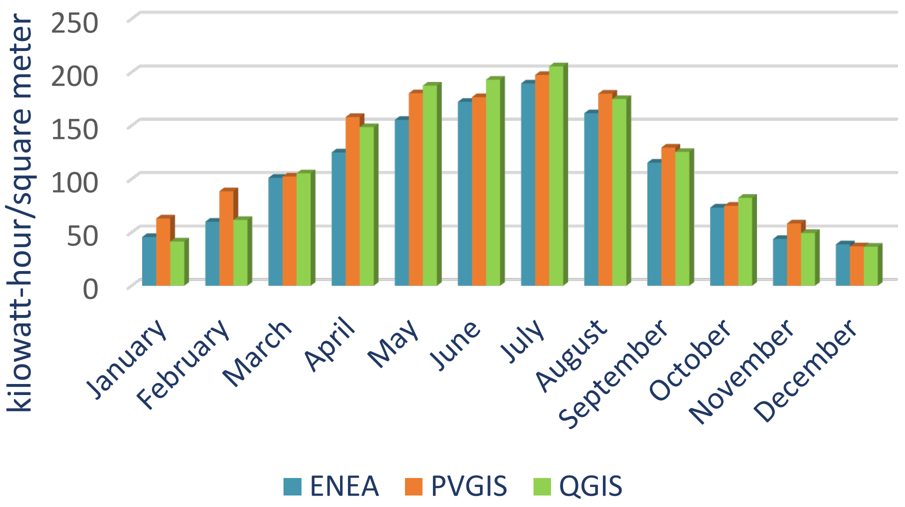
Id	Name	Alias	Type	Type name	Length	Precision	Comment
0	Jan_Wh/m2		double	Real	23	15	
1	Feb_Wh/m2		double	Real	23	15	
2	Mar_Wh/m2		double	Real	23	15	
3	Apr_Wh/m2		double	Real	23	15	
4	May_Wh/m2		double	Real	23	15	
5	Jun_Wh/m2		double	Real	23	15	
6	Jul_Wh/m2		double	Real	23	15	
7	Aug_Wh/m2		double	Real	23	15	
8	Sep_Wh/m2		double	Real	23	15	
9	Oct_Wh/m2		double	Real	23	15	
1	Nov_Wh/m2		double	Real	23	15	
1	Dec_Wh/m2		double	Real	23	15	

7. Monthly and Annual Relative Errors in Comparison to ENEA and PVGIS

$$(Irr_{ENEA/PVGIS} - Irr_{calc})/Irr_{ENEA/PVGIS}$$

Month	Horizontal Solar Irradiation			Unit	Error in Comparison to		Error in Comparison to	
	ENEA	PVGIS	QGIS		ENEA	PVGIS	ENEA (%)	PVGIS (%)
January	45.57	62.95	41.38	KWh/m^2	0.0919	0.3426	9.19	34.26
February	59.92	88.47	61.58	KWh/m^2	-0.0276	0.3040	-2.76	30.40
March	101.06	102.27	105.25	KWh/m^2	-0.0415	-0.0291	-4.15	-2.91
April	124.8	157.95	148.53	KWh/m^2	-0.1902	0.0596	-19.02	5.96
May	155.31	180.23	187.37	KWh/m^2	-0.2064	-0.0396	-20.64	-3.96
June	172.2	176.59	192.94	KWh/m^2	-0.1205	-0.0926	-12.05	-9.26
July	189.41	197.36	205.39	KWh/m^2	-0.0844	-0.0407	-8.44	-4.07
August	161.51	179.84	174.84	KWh/m^2	-0.0825	0.0278	-8.25	2.78
September	115.2	129.34	125.27	KWh/m^2	-0.0874	0.0314	-8.74	3.14
October	73.16	74.88	82.26	KWh/m^2	-0.1244	-0.0986	-12.44	-9.86
November	43.8	58.29	49.31	KWh/m^2	-0.1259	0.1540	-12.59	15.40
December	38.75	36.88	36.53	KWh/m^2	0.0572	0.0094	5.72	0.94
Annual	1280.69	1445.05	1410.67	KWh/m^2	-0.1015	0.0238	10.15	2.38

Average Horizontal Solar Irradiation of Corio



8. Calculation of The Electric Photovoltaic Potential

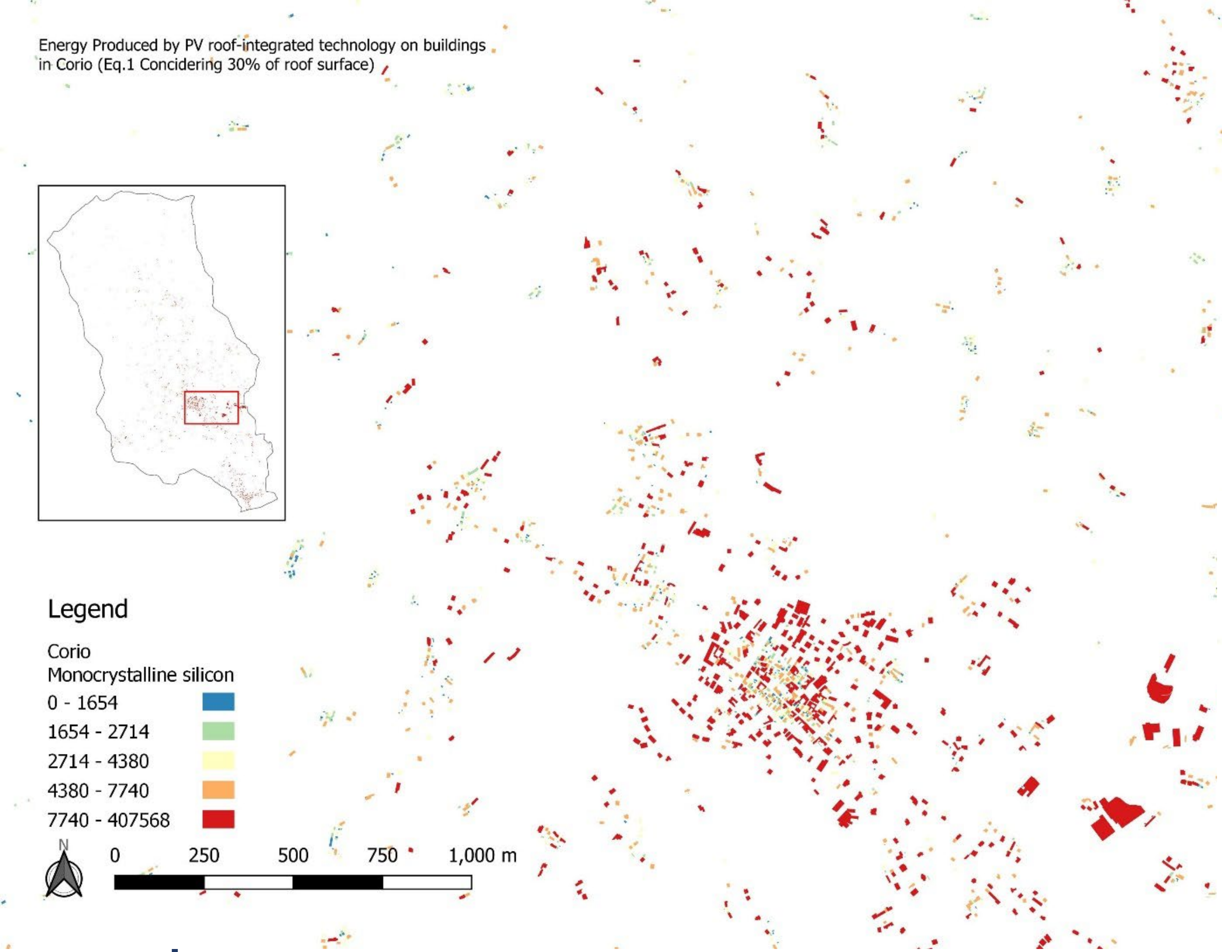
$$E = PR.H_S.S.\eta$$

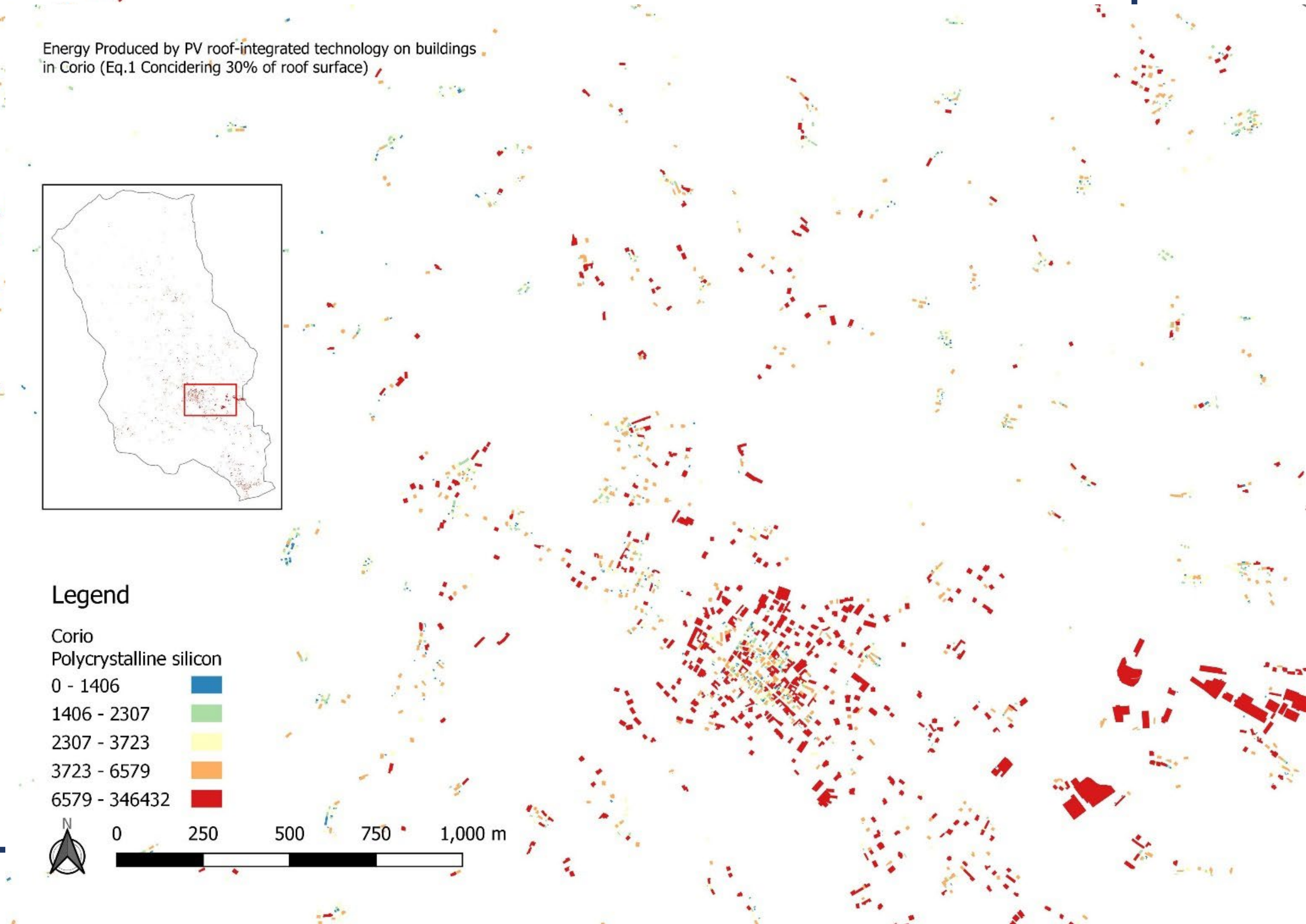
Monocrystalline silicon: η MC=20% (0.20)			Polycrystalline silicon: η PC =17% (0.17)			Thin film: η FS =10% (0.10)		
$E = PR\ H_s\ S\ \eta$			$E = PR\ H_s\ S\ \eta$			$E = PR\ H_s\ S\ \eta$		
	Sum (kWh/month)	Average (kWh/month)		Sum (kWh/month)	Average (kWh/month)		Sum (kWh/month)	Average (kWh/month)
January	1,116,884.89	189.46	January	949,352.81	161.04	January	558,442.15	94.73
February	1,624,720.58	275.61	February	1,381,012.79	234.27	February	812,360.23	137.80
March	2,717,659.30	461.01	March	2,310,010.75	391.86	March	1,358,829.83	230.51
April	3,758,304.03	637.54	April	3,194,558.45	541.91	April	1,879,151.42	318.77
May	4,698,841.62	797.09	May	3,994,015.44	677.53	May	2,349,420.79	398.54
Jun	4,794,775.78	813.36	Jun	4,075,559.52	691.36	Jun	2,397,387.93	406.68
July	5,151,790.73	873.93	July	4,379,021.48	742.84	July	2,575,895.29	436.96
August	4,420,651.99	749.90	August	3,757,554.53	637.41	August	2,210,325.70	374.95
September	3,211,953.72	544.86	September	2,730,160.59	463.13	September	1,605,976.51	272.43
October	2,150,265.39	364.76	October	1,827,725.67	310.05	October	1,075,132.89	182.38
November	1,333,476.92	226.20	November	1,133,455.13	192.27	November	666,738.51	113.10
December	978,311.80	165.96	December	831,565.31	141.06	December	489,156.08	82.98
Annual	**35,957,673.00 (kWh/year)**	**6,099.69 (kWh/year)**	Annual	**30,563,993.09 (kWh/year)**	**5,184.73 (kWh/year)**	Annual	**17,978,819.82 (kWh/year)**	**3,049.84 (kWh/year)**

~36,000,000 kWh/year **~31,000,000 kWh/year** **~18,000,000 kWh/year**

Polycrystalline Silicon

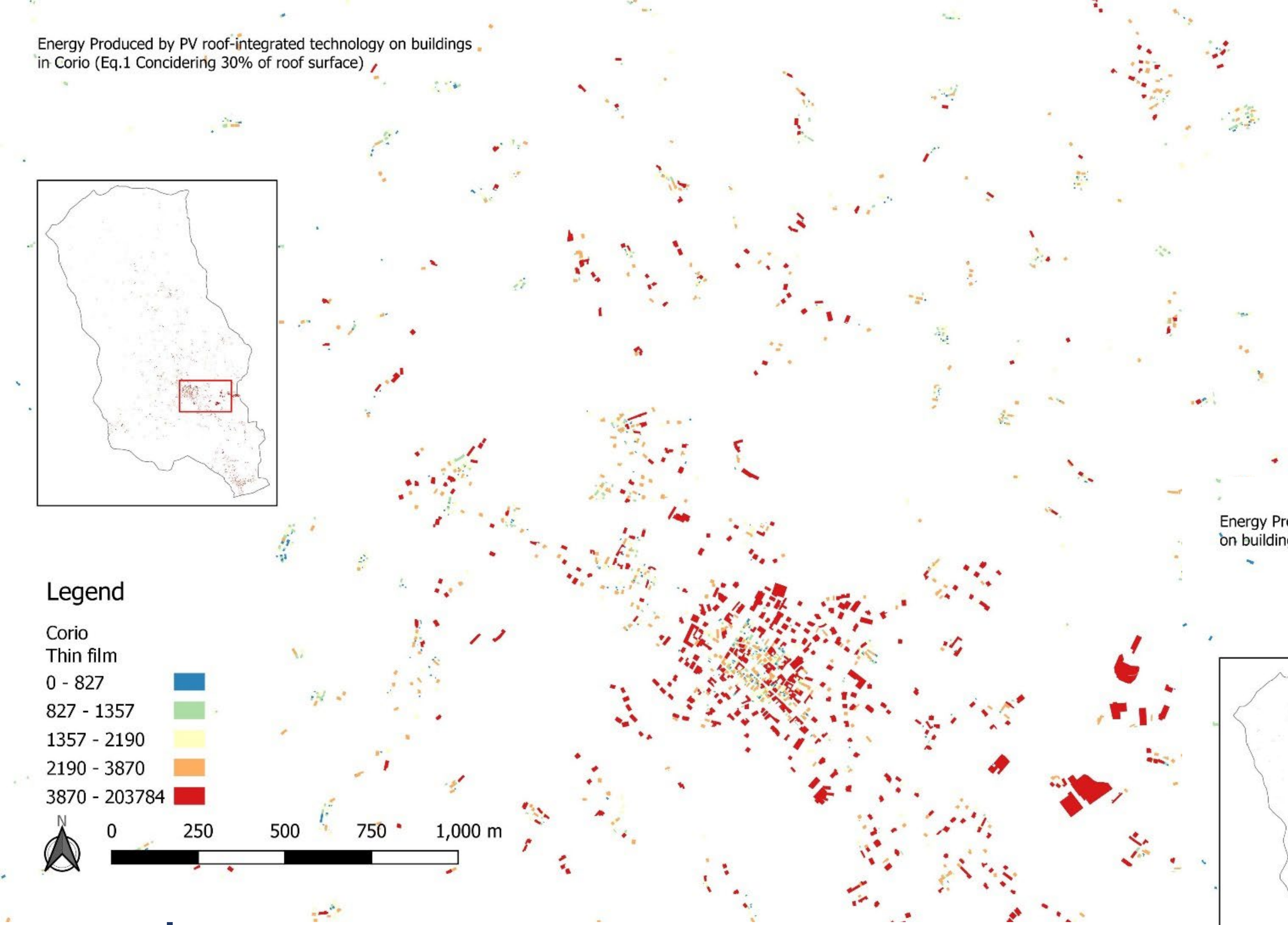
Monocrystalline Silicon



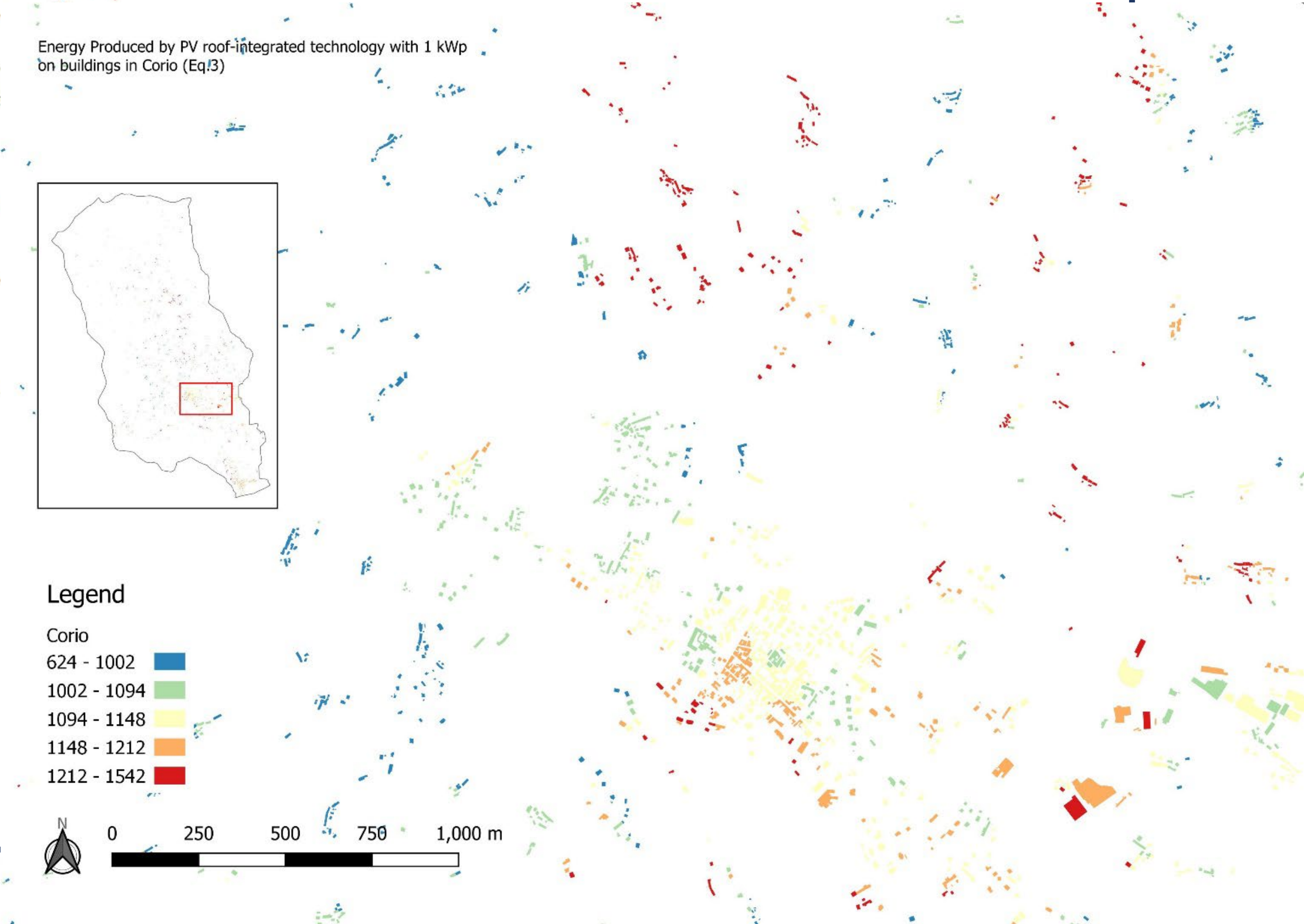


$$E_{1kWp} = PR.H_S.W_p/I_{stc}$$

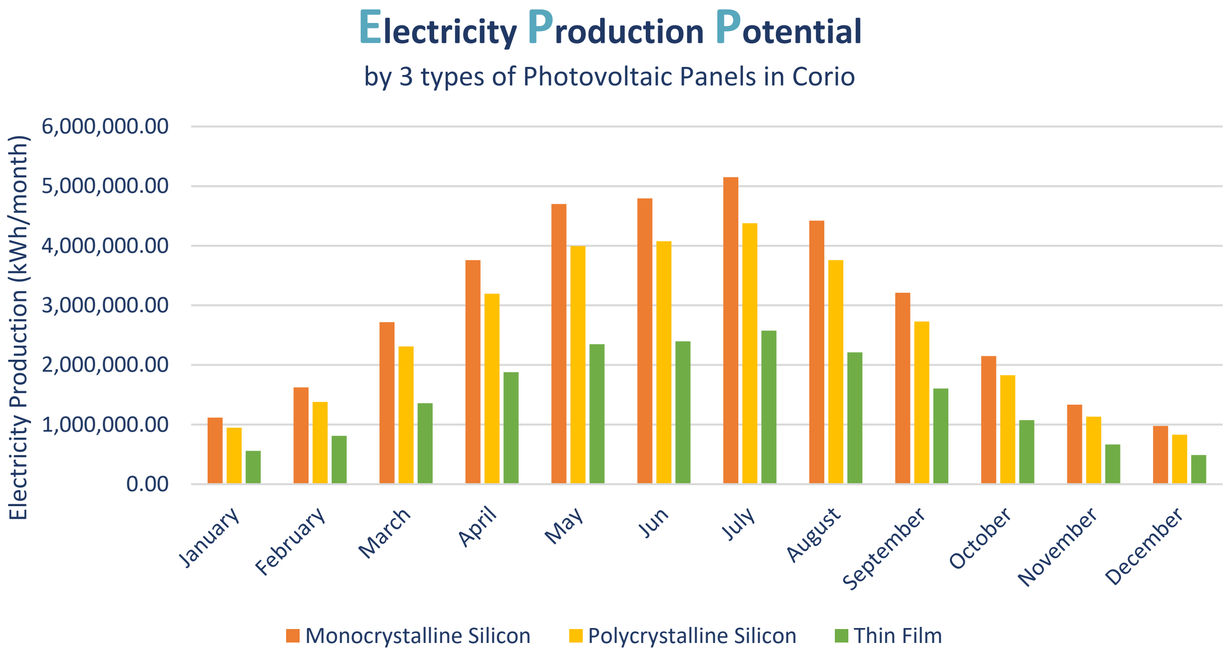
Tested Solar Irradiance Under Standard Test (I_{stc})

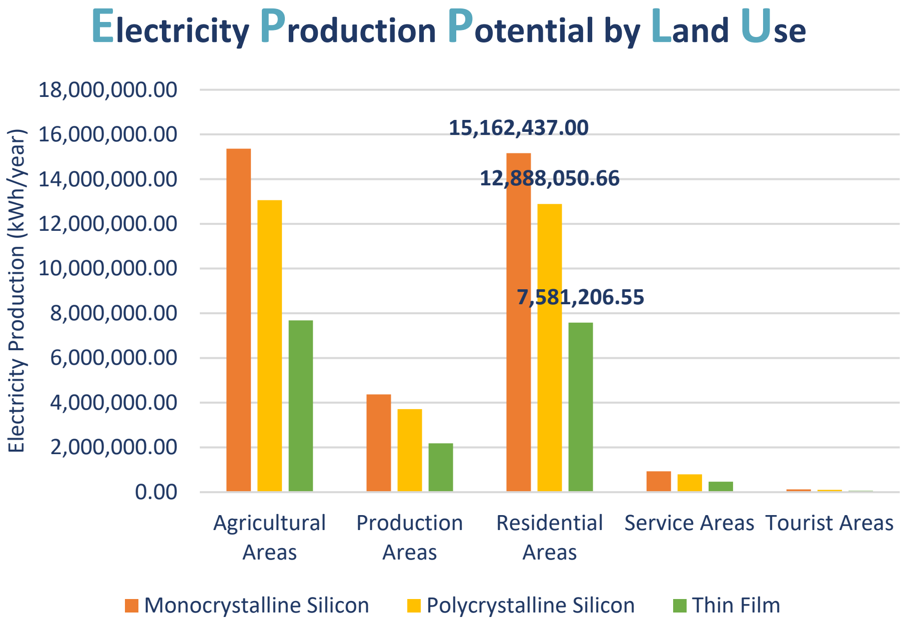


Thin Film



Electricity Production Potential Charts





9. Economic Analysis

1. Corio's Electric Consumption

$E_{el} = E_{el,pro\ capita} \cdot Number\ of\ familie$	Min $E_{el,\ pro\ capita}$ (2200 kWh/year)	Max $E_{el,\ pro\ capita}$ (2500 kWh/year)
Number of Families	(3,260 / 2.5) = 1304 Families	
Total E_{el} consumption (kWh/year)	2,868,800	3,260,000

2. Corio's Electric Production and Consumption Differential

PV Technology	Total $E_{el,\ PV}$ (kWh/year)	$E_{el,\ user}$ (kWh/year)	$E_{el,\ PV} - E_{el,\ user}$	Status
Monocrystalline Silicon	15,162,437.00	2,868,800	12,293,637.00	> 0
		3,260,000	11,902,437.00	> 0
Polycrystalline Silicon	12,888,050.66	2,868,800	10,019,250.66	> 0
		3,260,000	9,628,050.66	> 0
Thin Film	7,581,206.55	2,868,800	4,712,406.55	> 0
		3,260,000	4,321,206.55	> 0

Then $R = E_{el,\ user} \cdot 0.22 + (E_{el,\ PV} - E_{el,\ user}) \cdot 0.10$

Assumptions:

1. Only Residential Buildings
2. Two and Half Person per Family
3. 30% of Rooftops = A_C

3. Cost of Investments

$C_{inv,\ PV}$	
(C_{pv} = 1800 € / kWp) , $kW_p = A_C$ / 6 – 8 m²	
(1800*67,382.14)/6	(1800*67,382.14)/8
20,214,642.00 (€)	**15,160,981.50 (€)**

Potential PV Power (kWp) = A_C m² / 6~8 m²

$$C_{inv} = C_{pv} \cdot kW_p$$

4. Simple Payback Time

PV Technology	R (€/year)	SPT (year) $C_{inv,\ PV}$: 20,214,642.00	SPT (year) $C_{inv,\ PV}$: 15,160,981.50
Monocrystalline Silicon	1,907,443.70	10.6	**7.9**
	1,860,499.70	10.9	8.1
Polycrystalline Silicon	1,680,005.07	12.0	9.0
	1,633,061.07	12.4	9.3
Thin Film	1,149,320.66	17.6	13.2
	1,102,376.66	18.3	13.8

$$SPT = C_{inv,PV} / R$$

Conclusion

1. ~18,000 to ~36,000 MWh/year Electricity Production Using 3 Type of Photovoltaic Panels
2. Generated Revenue by Photovoltaic Technology Between ~ **1.1 to 1.9** million €/year
3. Payback Time Around 8 to 18.5 years. Acceptable Less Than 20 years According to Photovoltaic Lifespan
4. Recommended Monocrystalline Silicon Photovoltaic Panels Which Recovers in 8 years

Exercise Three: Forestry Biomass Potential

Purpose:

Calculation of Biomass Electricity and Thermal Production Potential in Corio Municipality. And its Sufficiency and Efficiency for Corio.

Introduction

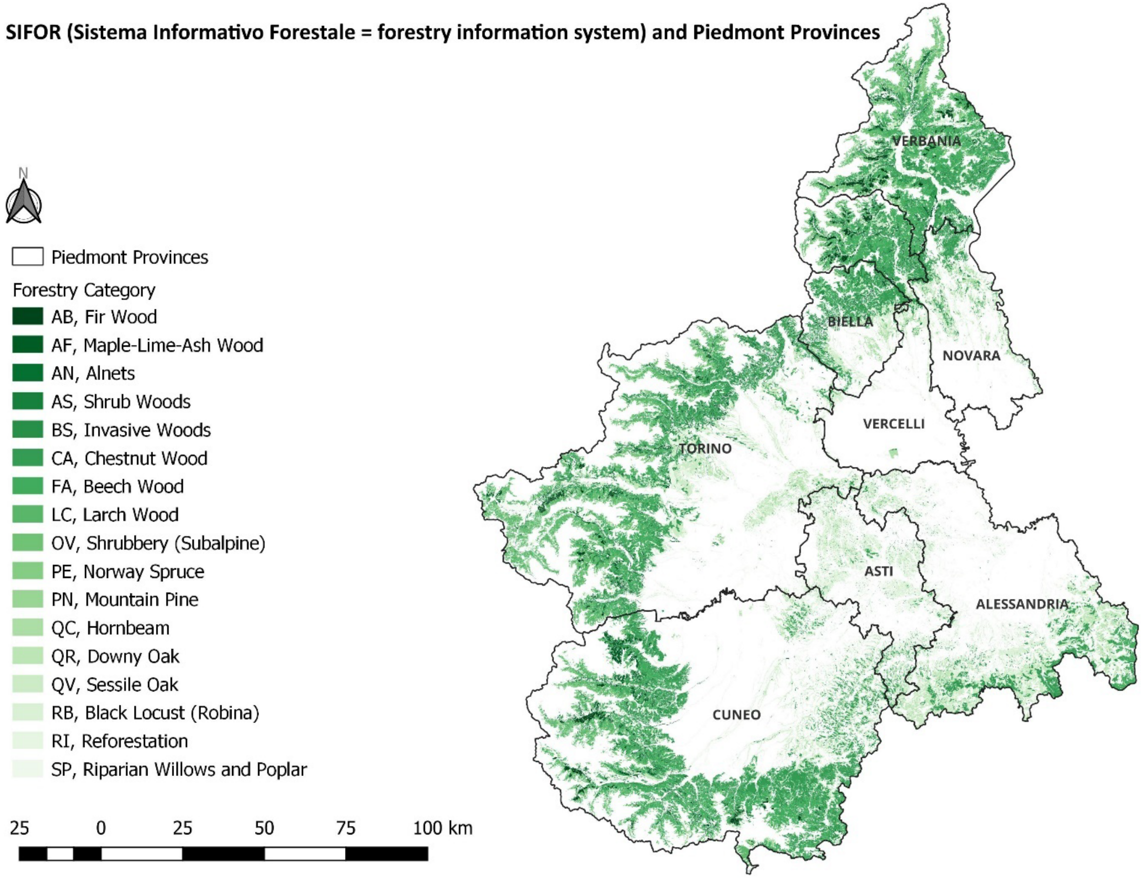
Biomass is renewable organic material that comes from plants and animals.

When it comes to **energy**, biomass is any organic matter that can be used to generate energy, for example **wood, forest residues or plant materials**.

Forestry information in the **Piedmont region** obtained from **Sifor**.

Corio is a commune (municipality) in the Metropolitan City of Turin in the Italian region of Piedmont, located about 30 kilometers northwest of Turin. The population of this city has been reported **3,260** in 2017.

SIFOR (Sistema Informativo Forestale = forestry information system) and Piedmont Provinces



Corio's Accessible Biomass Area Calculation Prerequisites

Forest Area Extraction

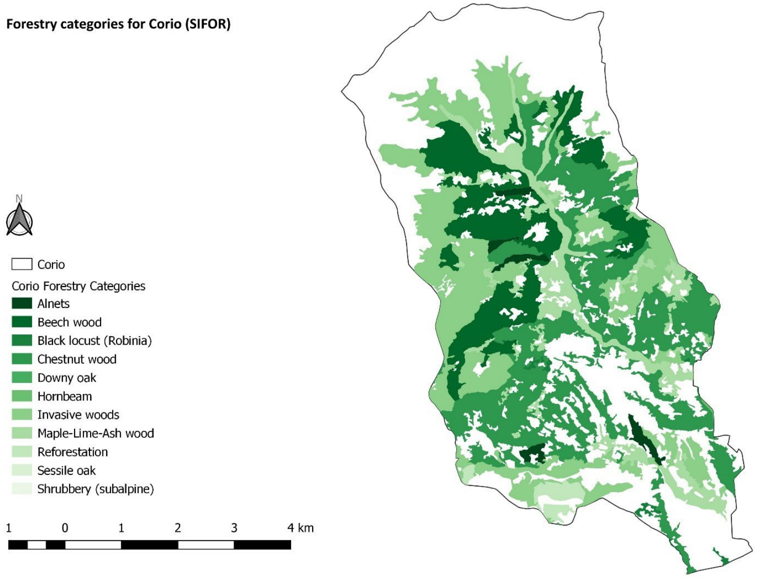
1. Cutting Corio's Forest Area from Sifor
2. Categorizing Forestry
3. Calculating every category by Square Meter and Hectare

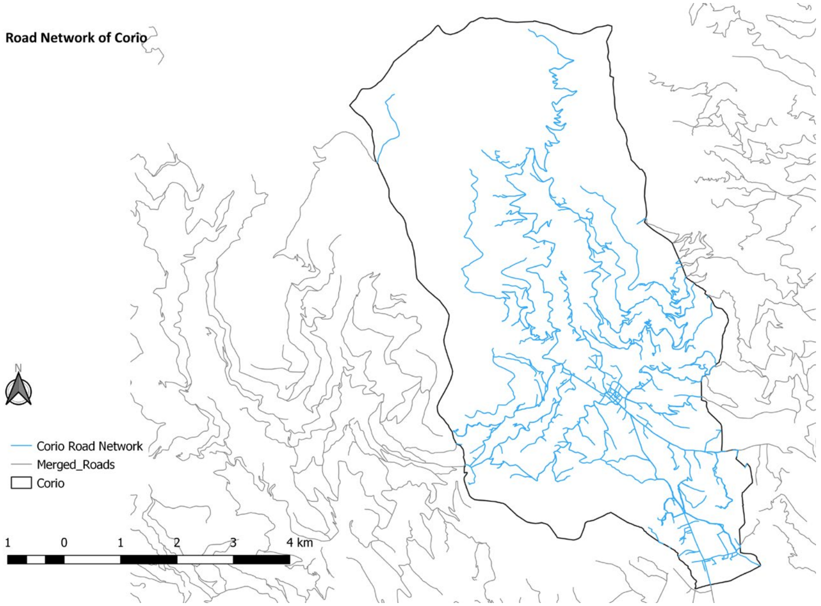
Road Networks

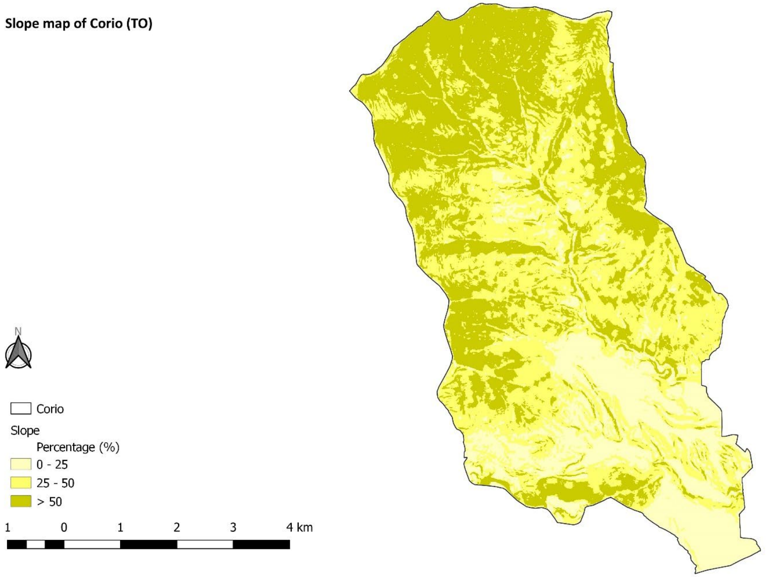
1. Identifying Torino Road Function
2. Merging Road Network
3. Cutting Corio's Road Networks

Slope Calculation

1. Calculating Corio's Slope from DTM
2. Segregating Slope into Three Intervals [0 - 25], [25 - 50], [50 - 75]
3. Converting Raster Data to Vector Data





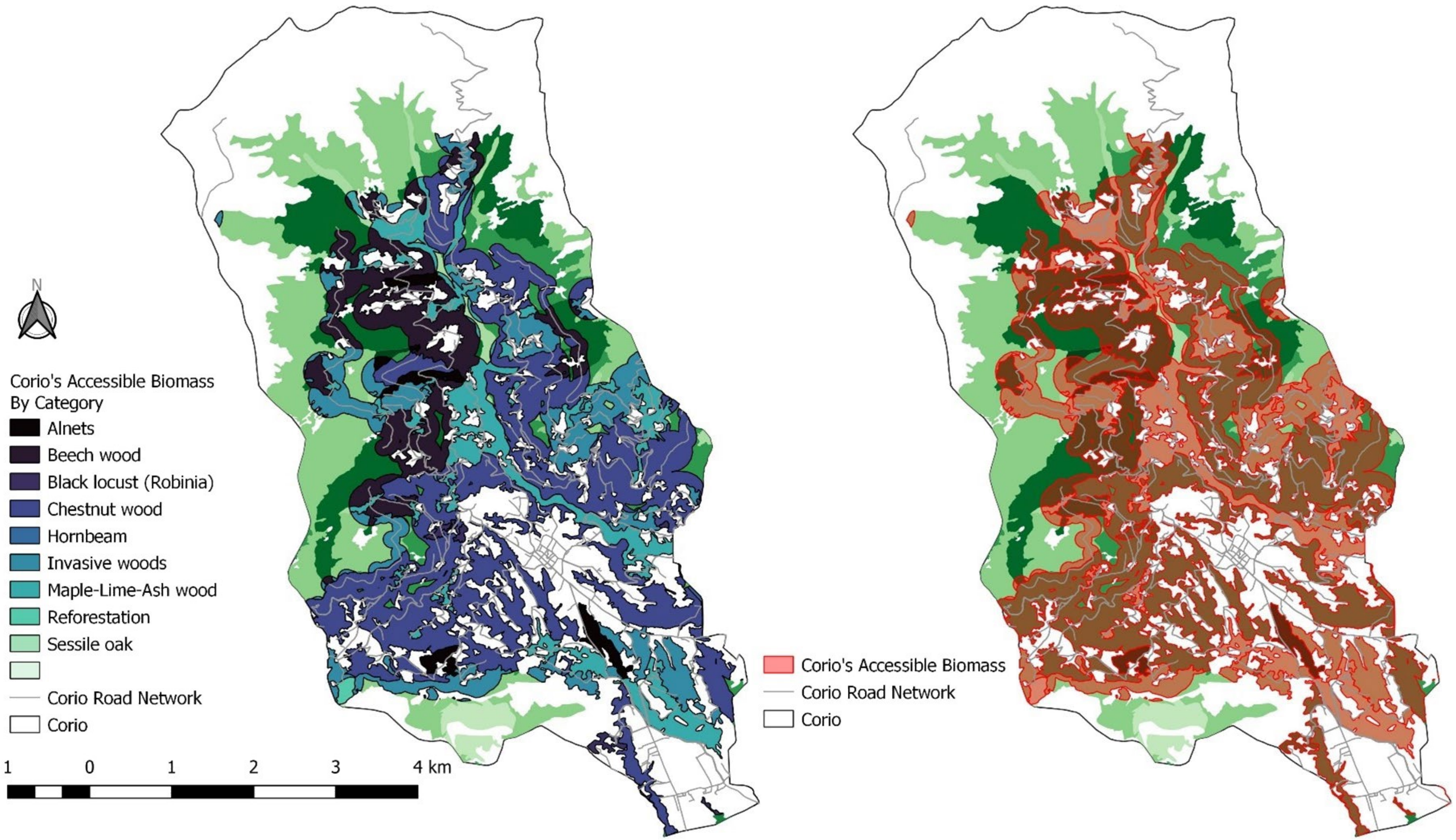


Corio's Accessible Biomass Area Calculation

Accessible Biomass Area

is the surrounding area of the road network, which is covered by woodlands to extract biomass. The radius of this area is signified by the slope. The more the slope percentage, the less radius of accessibility. The plane areas have a maximum accessibility of 250 meters.

1. Cutting Corio's Road Network from Slope Vector Layers
2. Assigning Buffer Zones to The Cropped Road Network Layers
3. Merging Buffer Zone Layers
4. Using The Merged Layer to Clip Corio's Sifor



Thermal and Electrical and Heating Energy Production Calculation

Potential Biomass Production

$$m_c = A \cdot p \cdot 10^{+3} \qquad (kg_{ss}/year)$$

*Where A (ha) is Accessible Area and p (t/ha.year) is Annual Productivity

Thermal Energy Production

$$E_{Th} = m_c \cdot H \qquad (kWh/year)$$

*Where H (kWh/kg_{db}) is Lower Heating Value of Dry Biomass

Electrical Energy Production

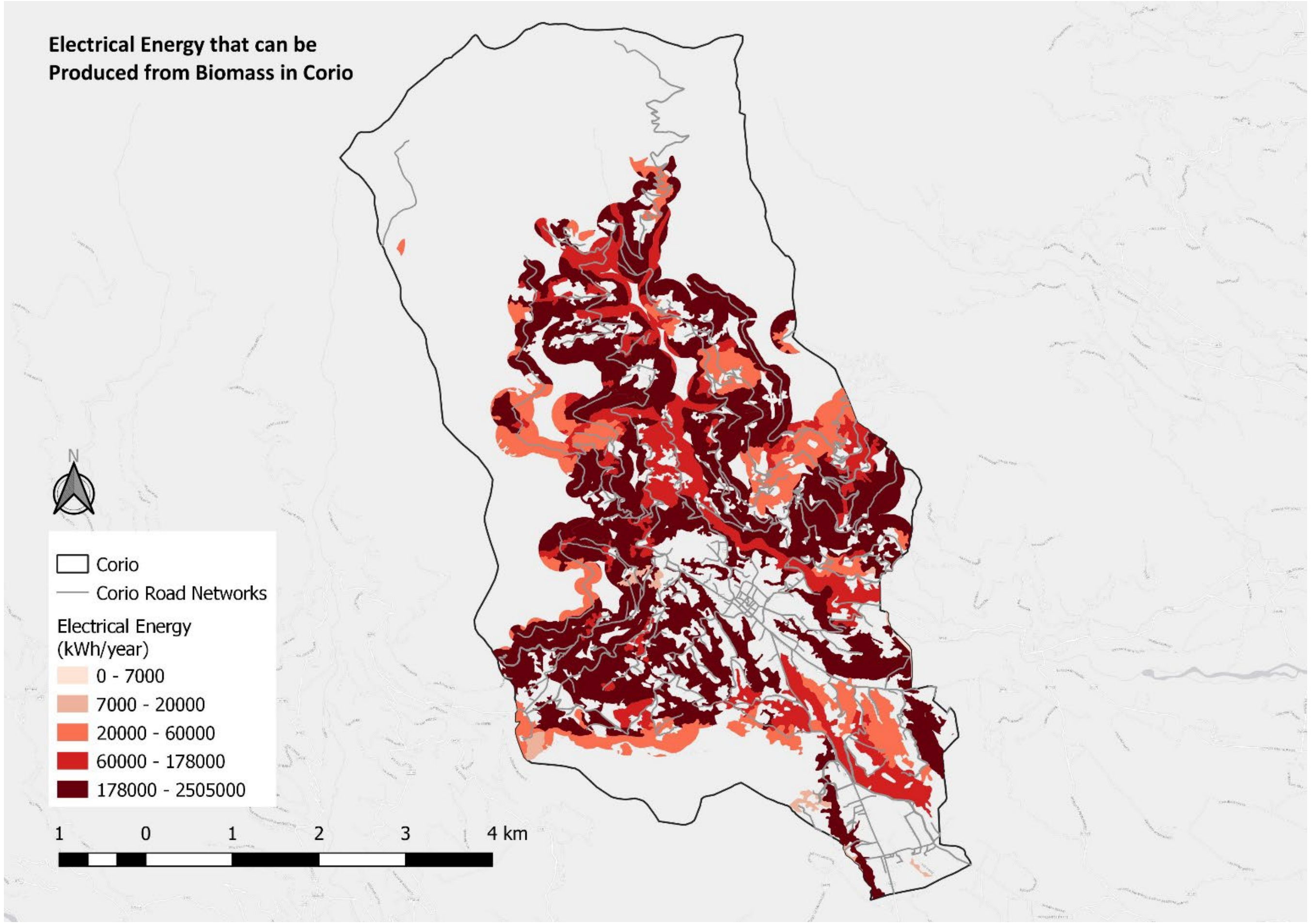
$$E_{el} = E_{Th} \cdot \eta_{el} \qquad (kWh_{el}/year)$$

*Where η_{el} is Electrical Efficiency of The Biomass Plant

Heating Energy Production

$$E_{heat} = E_{Th} \cdot \eta_{heat} \qquad (kWh_{th}/year)$$

*Where η_{heat} is System Efficiency of The Biomass Plant



Thermal and Electrical and Heating Energy Production Calculation

COD	CATEGORY	Area (ha)	Density (kg/m^3)	*P* (t/ha)	H (kWh/kg)	Available Biomass (t)	Mass Extracted (mc/year)	m_c (kg_{ss}/year)	E_{Th} (kWh_t/year)	E_{el} (kWh_{el}/year)	E_{heat} (kWh_{el}/year)
CA	Chestnut Wood	775.47	540	3.23	4	2,504.77	4,638.46	2,504,770	10,019,080	2,504,770	7,514,310
AF	Maple – Lime – Ash Wood	282.32	650	0.36	4.1	101.64	156.37	101,640	416,724	104,181	312,543
BS	Invasive Wood	297.04	500	0.14	4	41.59	83.18	41,590	166,360	41,590	124,770
FA	Beach Wood	256.02	730	1.13	4	289.30	396.30	289,300	1,157,200	289,300	867,900
AN	Alnets	45.46	620	1.39	4.1	63.19	101.92	63,190	259,079	64,769	194,309
RB	Black Locust (Robinia)	13.02	760	0.98	4.5	12.76	16.79	12,760	57,420	14,355	43,065
QC	Hornbeam	1.09	800	0.64	4.2	0.7	0.88	700	2,940	735	2,205
RI	Reforestation	5.32	500	2.03	4	10.80	21.60	10,800	43,200	10,800	32,400
QV	Sessile Oak	0.00	760	0.66	4.2	0	0	0	0	0	0
Total		1,675.74				3,024.75	5,415.50	3,024,750	12,122,003	3,030,500	9,091,502

Corio's Heating and Electrical Energy Consumption Calculation

Corio's Electrical Energy Consumption

Assuming that the average electrical energy consumption of an Italian family consisting of about 2 - 2.5 people (components) is equal to 2200-2500 (kWh_{el}/year) and the population of Corio is 3260

	Electric Consumption Per Family (kWh_{el}/year)	Number of Families	Total electric Consumption (kWh/Year)
Low Consumption	2,200	1,304	**2,868,800**
High Consumption	2,500	1,630	**4,075,000**

Corio's Heating Energy Consumption

Considering the average thermal energy consumption to heat residential buildings for Torino is about 180 kWh/m²/year with **2617 HDD** at 20°C and Corio has **3291 HDD**:

180/2617*3291 = 226.36 kWh/m2/year

Buildings Function	Area (m²)	Energy Consumption for Space Heating (kWh/year)	Energy Consumption (%)
Services Areas	12,373.56	2,800,879.04	2.59
Production Areas	37,622.34	8,516,192.88	7.88
Agricultural	203,603.39	46,087,663.36	42.66
Residential	**221,794.20**	**50,205,335.11**	**46.48**
Tourist	1,823.40	412,744.82	0.38
Total	477,216.89	108,022,815.22	100

Cost of Biomass Power Plant and Biomass Cost

Cost of Biomass Power Plant

*To supply **Electrical Energy** the electric meter installed for a typical Italian family is 3 kW/fam (or 4.5-6 kW/fam), and number of Corio's family between 1,304 to 1,630, then the cost of investment for the electrical energy is:

Number of Families		Cost of Electric Meter (kW/fam)	Power Plant Capacity Demand (kW)	Cost of Biomass Plant (€/kW)	Cost of Investment (€)
Low	1,304	3	3,912	540	**2,112,480**
High	1,582	6	9,492		**5,125,680**

*To supply **Energy for Space Heating** the power installed for typical residential buildings in Torino is 0.03 kW/m^3 (of net heated volume), and assuming the height of 3 m for residential buildings and 221,794.20 m^2 of area for Corio's residential buildings, then the cost of investment for space heating energy is:

Corio's Residential Buildings Area (m³)		Cost of installed power (kW/m³)	Cost of Biomass (kW)	Cost of Biomass Plant (€/kW)	Cost of Investment (€)
221,794.20 * 3	665,382.60	0.03	19961.48	540	**10,779,199.2**

Cost of Wooden Biomass

*Assuming that the total cost of **Wooden Biomass** for energy production (transport costs included) is 0,153 €/kg or 0,034 €/kWh (for wood chips):

COD	CATEGORY	m_c (kg_{ss}/year)	Total Cost of Wooden Biomass (€/year)	COD	CATEGORY	m_c (kg_{ss}/year)	Total Cost of Wooden Biomass (€/year)
CA	Chestnut Wood	2,504,770	383,229.8	RB	Black Locust (Robinia)	12,760	1,952.28
AF	Maple – Lime – Ash Wood	101,640	15,550.92	QC	Hornbeam	700	107.10
BS	Invasive Wood	41,590	6,363.27	RI	Reforestation	10,800	1,652.40
FA	Beach Wood	289,300	44,262.90	QV	Sessile Oak	0	0.00
AN	Alnets	63,190	9,668.07	Total		**3,024,750**	**462,786.75**

Economic Analysis for Electric Energy

***Scenario One:**

Electric Energy Production by Biomass: **3,030,500.00** (kWh/year)

Corio's Electric Energy Consumption: **4,075,000.00** (kWh/year)

Electric Energy Shortage: **1,044,500.00** (kWh/year)

Electric Energy Cost Before Biomass: 0.66 (€/kWh) . EC

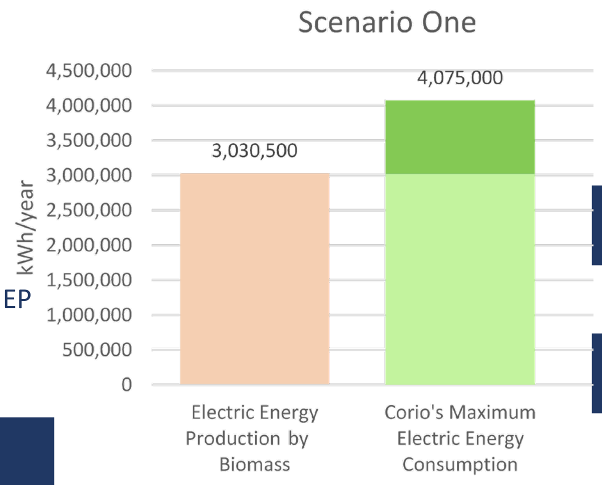
2,689,500.00 (€/year)

Electric Energy Cost After Biomass: 0.66 (€/kWh) . ESh + 0.034 (€/kWh) . EP

792,407.00 (€/year)

Electric Energy Saving: ECC(BB) – ECC(AB)

1,897,093.00 (€/year)



***Scenario Two:**

Electric Energy Production by Biomass: **3,030,500.00** (kWh/year)

Corio's Electric Energy Consumption: **2,868,800.00** (kWh/year)

Electric Energy Excess: **161,700.00** (kWh/year)

Electric Energy Cost Before Biomass: 0.66 (€/kWh) . EC

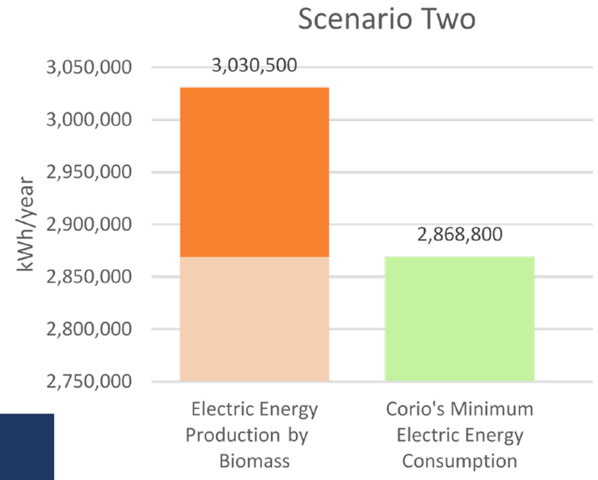
1,893,408.00 (€/year)

Electric Energy Cost After Biomass: 0.034 (€/kWh) . EC - 0.2 (€/kWh) . EE

65,199.20 (€/year)

Electric Energy Saving: ECC(BB) – ECC(AB)

1,828,208.80 (€/year)



***Pay Back Time:**

PBT (year) = C_{inv} (€) / ES (€/year)

PBT_{min} = 2,112,480 / 1,897,093.00

PBT_{min} = 1.2 (year) ~ 1.5 (year)

PBT_{max} = 5,125,680 / 1,828,208.80

PBT_{max} = 2.8 (year) ~ 3 (year)

Economic Analysis for Space Heating

Space Heating Energy Production by Biomass: **9,091,502.00** (kWh/year)

Corio's Space Heating Energy Consumption: **50,205,335.11** (kWh/year)

Space Heating Energy Shortage: **41,113,833.11** (kWh/year)

Space Heating Energy Cost Before Biomass:

0.0978 (€/kWh) . EC

4,910,081.77 (€/year)

Space Heating Energy Cost After Biomass:

0.0978 (€/kWh) . ESh + 0.034 (€/kWh) . EP

4,330,043.95 (€/year)

Space Heating Energy Saving:

ECC(BB) – ECC(AB)

580,037.82 (€/year)

***Pay Back Time:**

$PBT\ (year) = C_{inv}\ (€)\ /\ ES\ (€/year)$

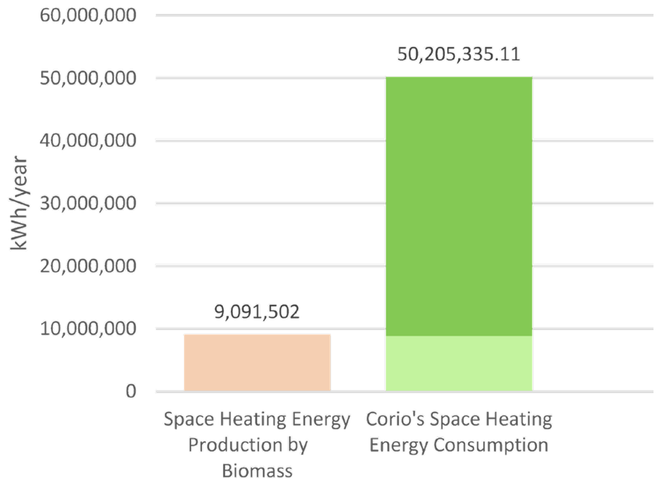
PBT = 10,779,199.20 / 580,037.82

PBT = 18.6 (year)

Ultimate Pay Back Time:

$PBT_{Ult} = (10{,}779{,}199.20 + 5{,}125{,}680)\ /\ (1{,}828{,}208.80 + 580{,}037.82)$

PBT_{Ult} = 6.6 (years)



Analysis of Territorial Constrains and Conclusion

1. **Corio** doesn't subject to any of the four **Territorial Constraints.**
2. **So** it is **advisable** to construct a **biomass power plant** to produce energy for space heating and electricity usage of **Corio municipality**.
3. **With the assistance** of a biomass power plant, we can generate about **12,000** MWh/year of thermal energy, and save up to **2.5** million € / year.
4. **The cost of investment** for this technology to supply space heating and electrical energy would recover in **6.6** years.

Exercise Four: Energy Performance of Residential Buildings

Purpose:

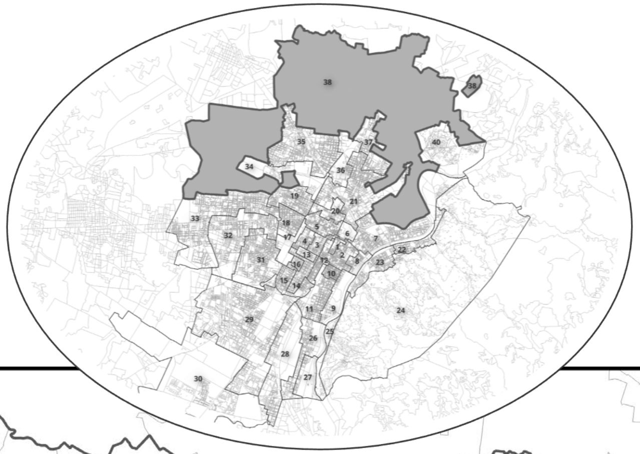
Calculation and Identification of The Energy Consumption of Torino Residential Buildings (Micro-Zone 38) and Consequently Practicing Retrofit Measures to Improve Energy Efficiency. And in the end, Providing Policies for the Best Way of Implementation of More Effective Measures.

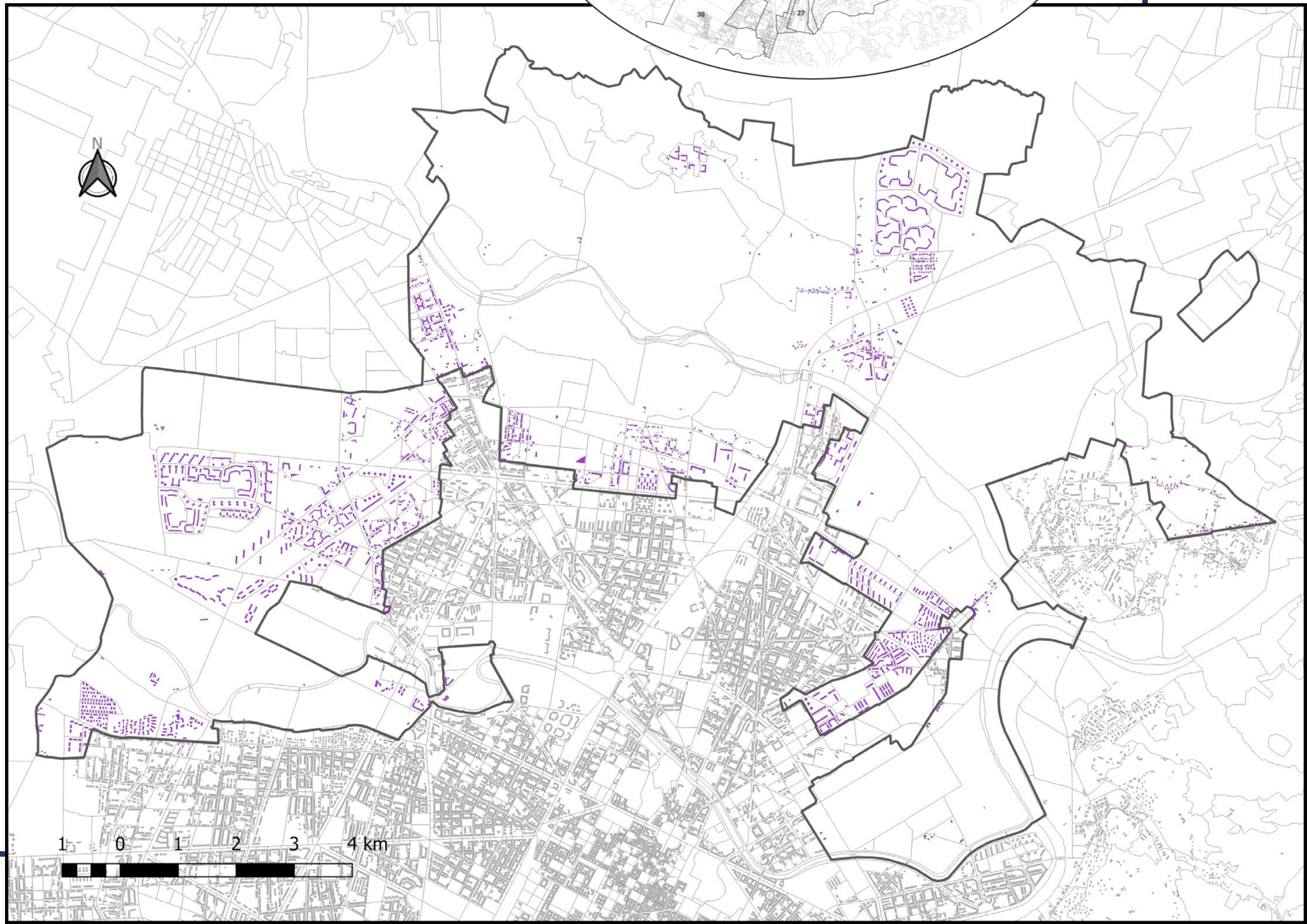
Introduction

Space Heating Energy Consumption depends mainly on Climate, Dimensions, Period of Construction, Buildings' Compactness, and Urban Density.

In this exercise, the Energy-Use Model of Residential Buildings at an Urban Scale will be applied to the 38th "Census Micro Zone" of Turin and some hypotheses of Energy Retrofit Measures will be identified through a Costs/Benefits Analysis.

This research describes a methodology based on an open-source QGIS tool to Estimate and then Distribute Energy Performance, Energy Consumption, and Energy-Saving Potential in the Metropolitan City of Turin Micro Zone 38.





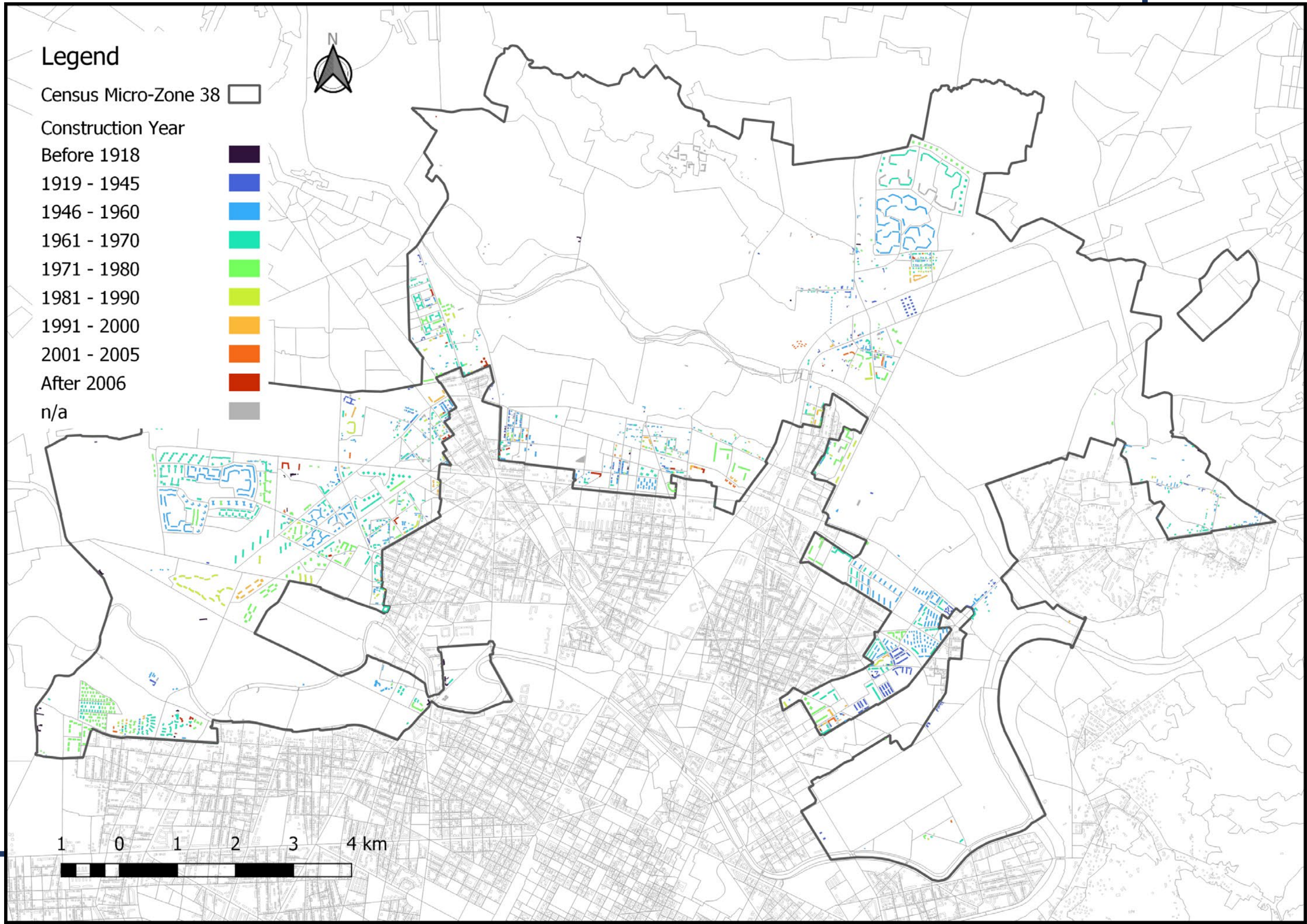
Energy Performance Index Calculation

1. Extracting Micro Zone 38 Residential Buildings
2. Categorizing Residential Buildings by Period of Construction
3. Heated Gross Volume (m^3) and Heat Loss Surface (m^2) Calculation

V = Area * Height

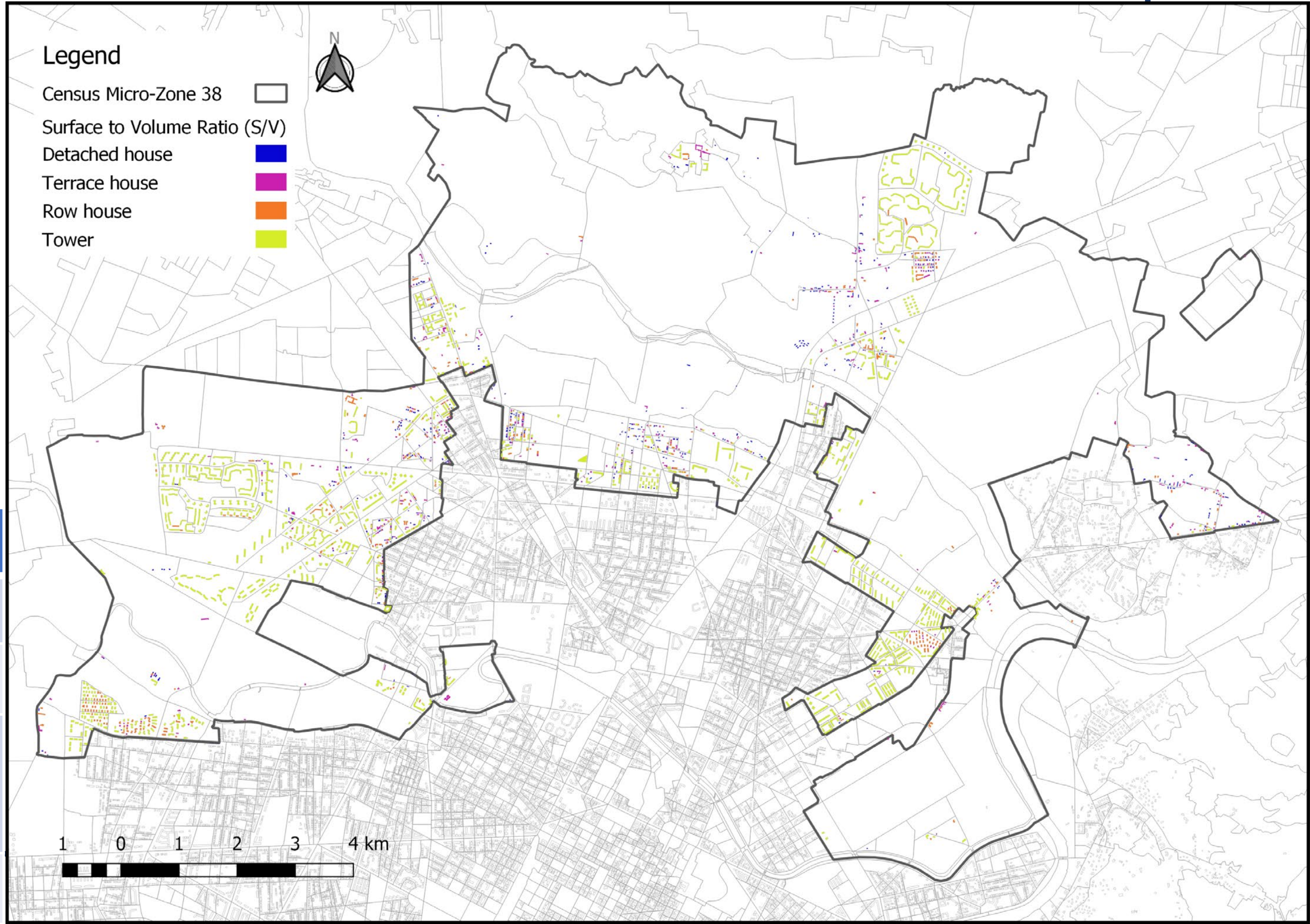
S = (Area * 2) + (Perimeter * Height)

4. Calculating Adjoined Walls Surface and Thickness and Subtracting them from Heat Loss Surface and Heated Gross Volume
5. Calculating Surface-to-Volume Ratio (S/V)



Energy Performance Index Calculation

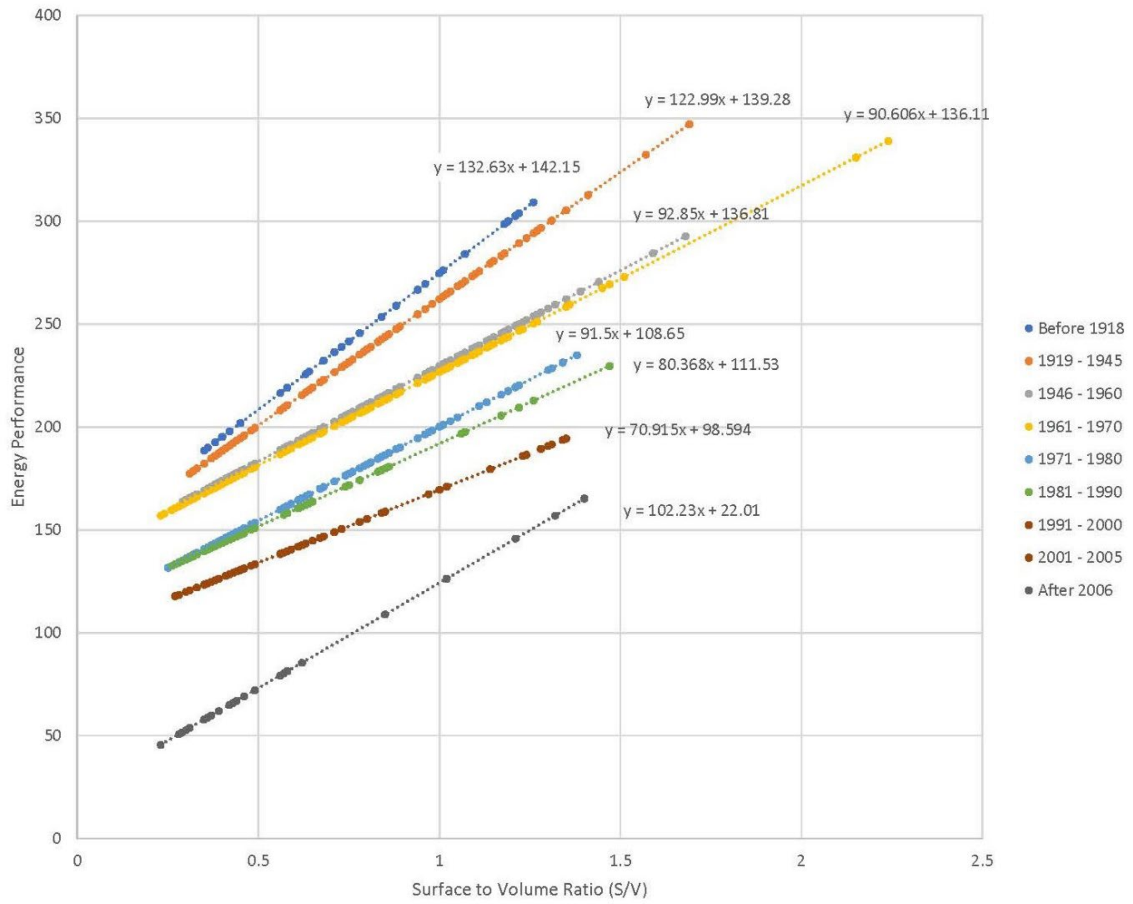
6. Classifying Buildings Types Based on Surface-to-Volume Ratio (S/V)
7. Multiplying Surface-to-Volume Ratio (S/V) by Factor According to its Typology to Calculate Real Surface-to-Volume Ratio $(S/V)_{real}$
8. Using Equations Respectfully to Period of Construction to Calculate Energy Performance Index (kWh/m^2/year)

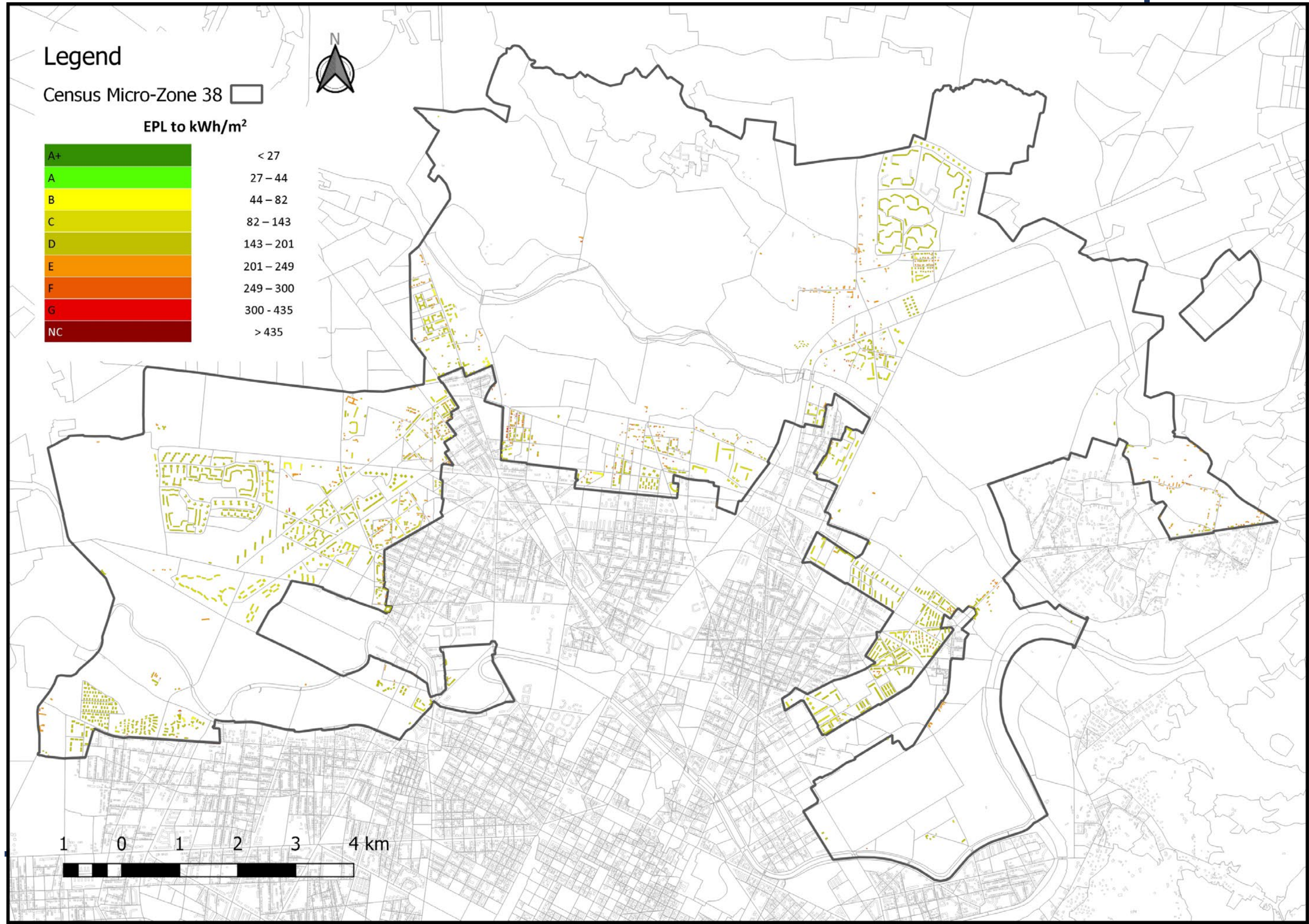


Period of Construction	Calculate Field	Period of Construction	Calculate Field
"PERIOD" = '< 1918'	$132.63 * (\frac{S}{V}) + 142.15$	"PERIOD" = '1971 - 1980'	$91.503 * (\frac{S}{V}) + 108.65$
"PERIOD" = '1919 - 1945'	$122.99 * (\frac{S}{V}) + 139.28$	"PERIOD" = '1981 - 1990'	$80.369 * (\frac{S}{V}) + 111.53$
"PERIOD" = '1946 - 1960'	$92.849 * (\frac{S}{V}) + 136.81$	"PERIOD" = '1991 - 2000' OR "PERIOD" = '2001 - 2005'	$70.915 * (\frac{S}{V}) + 98.594$
"PERIOD" = '1961 - 1970'	$90.606 * (\frac{S}{V}) + 136.11$	"PERIOD" = '> 2006'	$102.23 * (\frac{S}{V}) + 22.01$

Energy Performance Index Calculation

9. Classifying Buildings Using Scale Supplied by The D.G.R. n. 43-11965





Energy Consumption and Cost Calculation

1. Calculating the Number of Floors
2. Calculating Gross Heated Surface

GHS = Area * Number of Floors

3. Calculating f_n Factor to Calculate Useful Heated Area

$f_n = 0.9761 – 0.3055 * d_m$

Select by attribute	Average wall thickness (m):
"PERIOD" = '< 1950' *(< 1945)	0.5
"PERIOD" = '1950 - 1976' *(1946-1980)	0.3
"PERIOD" = '1976 - 1991' *(1981-1990)	0.35
"PERIOD" = '1991 – 2006' *(> 1991)	0.4

4. Calculating Useful Heated Area

UHA = GHA * f_n

5. Calculating Energy Consumption (kWh/year) and Cost (€)

EC = EP * UHA

ECC = EC * District Heating (Biomass) Average Unit Price

Fuel	Average unit price	Average price per kWh	Comparison %
Diesel	€1.755/litre	€0.176	100%
Liquid gas (in tank)	€3.519/kg	€0.275	157%
Natural gas (enhanced protection service)	€2.916/m³	€0.298	170%
Pellets	0.7985 €/kg	€0.166	95%
Wood chips (chips)	€0.153/kg	€0.034	19%
Chopped wood (mixed)	€0.183/kg	€0.043	24%
District heating (biomass)*	€0.117/kWh	€0.117	67%

Status: October 1, 2022
all prices incl. VAT
* incl. possible annual fixed tax

Construction Period	Average Energy Performance (kWh/m² year)	Average $(S/V)_{real}$	Useful Heated Area (m²)	Energy Consumption (MWh/year)	Energy Consumption Cost (€)
Before 1918	242	0.75	25,507.27	5,499.99	643,498.37
1919 - 1945	230	0.74	140,920.87	28,162.07	3,294,962.56
1946 - 1960	199	0.67	697,452.42	124,417.68	14,556,868.56
1961 - 1970	189	0.58	1,027,592.64	174,935.62	20,467,467.19
1971 - 1980	155	0.51	832,358.51	116,267.73	13,603,324.47
1981 - 1990	152	0.50	281,245.26	38,885.99	4,549,660.72
1991 - 2000	136	0.53	140,054.25	17,614.32	2,060,875.36
2001 - 2005	153	0.76	48,163.07	6,117.49	715,746.86
After 2006	74	0.51	95,344.28	5,342.00	625,013.95
Total	-	-	3,263,131.30	**517,242.89**	**60,517,418.04**

Energy Consumption Retrofit Calculation

Period of construction	EPgl,m kWh/(m²K)	Windows substitution	Roof insulation	Lower slab insulation	Vertical walls insulation	Overall retrofit
< 1919	271	17%	24%	9%	-	43%
1919-45	251	17%	26%	8%	-	42%
1946-60	239	15%	17%	4%	-	30%
1961-70	207	20%	17%	5%	29%	66%
1971-80	160	25%	14%	10%	26%	63%
1981-90	141	21%	14%	8%	30%	66%
1991-2005	113	12%	10%	5%	34%	57%

Energy Consumption Retrofit Effect Table

Period of Construction	EC Before Retrofit (MWh/year)	EC After Windows Substitution (MWh/year)	EC Saving After Windows Substitution (MWh/year)
Before 1918	5,499.99	4,564.99	935.00
1919 - 1945	28,162.07	23,374.52	4,787.55
1946 - 1960	124,417.68	105,755.03	18,662.65
1961 - 1970	174,935.62	139,948.49	34,987.12
1971 - 1980	116,267.73	87,200.80	29,066.93
1981 - 1990	38,885.99	30,719.93	8,166.06
1991 - 2000	17,614.32	15,500.60	2,113.72
2001 - 2005	6,117.49	5,383.40	734.10
After 2006	5,342.00	5,342.00	0.00
Total	**517,242.89**	**417,789.76**	**99,453.13**

Energy Consumption After Windows Substitution Retrofit Table

Period of Construction	EC Before Retrofit (MWh/year)	EC After Roof Insulation (MWh/year)	EC Saving After Roof Insulation (MWh/year)
Before 1918	5,499.99	4,179.99	1,320.00
1919 - 1945	28,162.07	20,839.93	7,322.14
1946 - 1960	124,417.68	103,266.67	21,151.01
1961 - 1970	174,935.62	145,196.56	29,739.05
1971 - 1980	116,267.73	99,990.25	16,277.48
1981 - 1990	38,885.99	33,441.95	5,444.04
1991 - 2000	17,614.32	15,852.89	1,761.43
2001 - 2005	6,117.49	5,505.75	611.75
After 2006	5,342.00	5,342.00	0.00
Total	**517,242.89**	**433,615.99**	**83,626.90**

Energy Consumption After Roof Insulation Retrofit Table

Energy Consumption Retrofit Calculation

Period of Construction	EC Before Retrofit (MWh/year)	EC After Vertical Walls Insulation (MWh/year)	EC Saving After Vertical Walls Insulation (MWh/year)
Before 1918	5,499.99	5,499.99	0.00
1919 - 1945	28,162.07	28,162.07	0.00
1946 - 1960	124,417.68	124,417.68	0.00
1961 - 1970	174,935.62	124,204.29	50,731.33
1971 - 1980	116,267.73	86,038.12	30,229.61
1981 - 1990	38,885.99	27,220.19	11,665.80
1991 - 2000	17,614.32	11,625.45	5,988.87
2001 - 2005	6,117.49	4,037.55	2,079.95
After 2006	5,342.00	5,342.00	0.00
Total	**517,242.89**	**416,547.34**	**100,695.55**

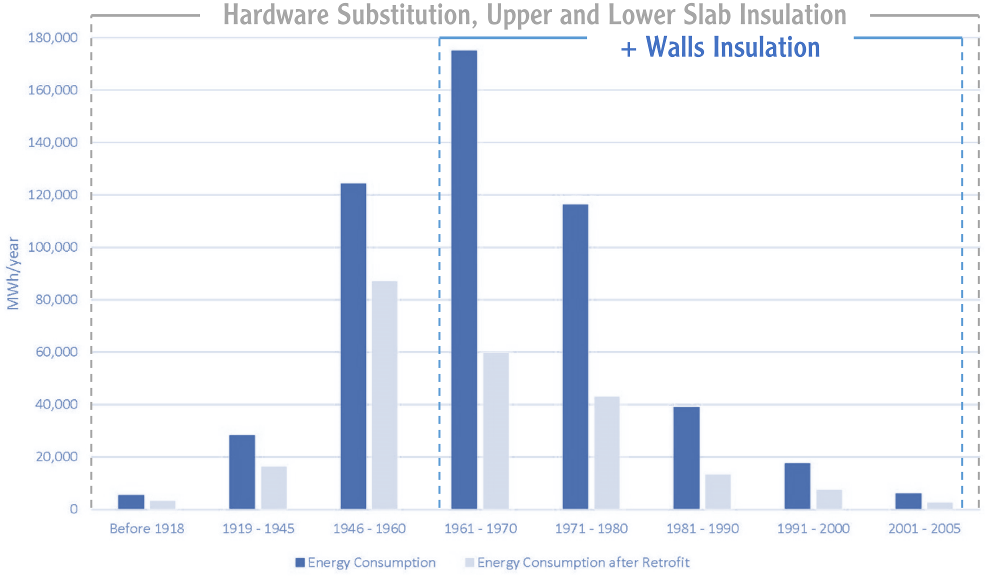
Energy Consumption After Vertical Walls Insulation Retrofit Table

Period of Construction	EC Before Retrofit (MWh/year)	EC After Lower Slab Insulation (MWh/year)	EC Saving After Lower Slab Insulation (MWh/year)
Before 1918	5,499.99	5,004.99	495.00
1919 - 1945	28,162.07	25,909.11	2,252.97
1946 - 1960	124,417.68	119,440.97	4,976.71
1961 - 1970	174,935.62	166,188.84	8,746.78
1971 - 1980	116,267.73	104,640.96	11,626.77
1981 - 1990	38,885.99	35,775.11	3,110.88
1991 - 2000	17,614.32	16,733.60	880.72
2001 - 2005	6,117.49	5,811.62	305.87
After 2006	5,342.00	5,342.00	0.00
Total	**517,242.89**	**484,847.19**	**32,395.70**

Energy Consumption After Lower Slab Insulation Retrofit Table

Period of Construction	EC Before Retrofit (MWh/year)	EC After Overall Retrofit (MWh/year)	EC Saving After Overall Retrofit (MWh/year)
Before 1918	5,499.99	3,134.99	2,364.99
1919 - 1945	28,162.07	16,334.00	11,828.07
1946 - 1960	124,417.68	87,092.38	37,325.30
1961 - 1970	174,935.62	59,478.11	115,457.51
1971 - 1980	116,267.73	43,019.06	73,248.67
1981 - 1990	38,885.99	13,221.24	25,664.75
1991 - 2000	17,614.32	7,574.16	10,040.16
2001 - 2005	6,117.49	2,630.52	3,486.97
After 2006	5,342.00	5,342.00	0.00
Total	**517,242.89**	**237,826.46**	**279,416.43**

Energy Consumption After Overall Retrofit Table



Energy Consumption Cost and Energy Performance After Retrofit Calculation

Construction Period	Energy Consumption Cost Saving (€/year) After				
	Windows Substitution	Roof Insulation	Lower Slab Insulation	Vertical Wall Insulation	Overall Retrofit
Before 1918	€ 109,394.73	€ 154,439.62	€ 57,914.86	€ 0.00	€ 276,704.31
1919 - 1945	€ 560,143.63	€ 856,690.25	€ 263,597.00	€ 0.00	€ 1,383,884.25
1946 - 1960	€ 2,183,530.28	€ 2,474,667.65	€ 582,274.74	€ 0.00	€ 4,367,060.56
1961 - 1970	€ 4,093,493.43	€ 3,479,469.41	€ 1,023,373.36	€ 5,935,565.47	€ 13,508,528.32
1971 - 1980	€ 3,400,831.12	€ 1,904,465.43	€ 1,360,332.45	€ 3,536,864.36	€ 8,570,094.42
1981 - 1990	€ 955,428.75	€ 636,952.50	€ 363,972.86	€ 1,364,898.21	€ 3,002,776.06
1991 - 2000	€ 247,305.04	€ 206,087.54	€ 103,043.77	€ 700,697.63	€ 1,174,698.96
2001 - 2005	€ 85,889.62	€ 71,574.69	€ 35,787.34	€ 243,353.93	€ 407,975.71
After 2006	€ 0.00	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Total	**€ 11,636,016.60**	**€ 9,784,347.08**	**€ 3,790,296.37**	**€ 11,781,379.60**	**€ 32,691,722.59**

Energy Consumption Cost and Saving After Retrofit

*Energy Consumption multiplied by district heating cost which is 0.117 €

Energy Performance Change After Retrofit

Construction Period	$(S/V)_{real}$	Useful Heated Area (m^2)	Average Energy Performance (kWh/m^2 year)		Average Energy Performance After Retrofit (kWh/m^2 year)	
Before 1918	0.75	25,507.27	242	E	138	C
1919 - 1945	0.74	140,920.87	230	E	133	C
1946 - 1960	0.67	697,452.42	199	D	139	C
1961 - 1970	0.58	1,027,592.64	189	D	64	B
1971 - 1980	0.51	832,358.51	155	D	55	B
1981 - 1990	0.50	281,245.26	152	D	52	B
1991 - 2000	0.53	140,054.25	136	C	59	B
2001 - 2005	0.76	48,163.07	153	D	66	B
After 2006	0.51	95,344.28	74	B	74	B

Cost of Intervention Calculation

Technology/Action	Unit Installed Surface (m^2)	Number of Interventions	Investment (M€)	Saving (GWh/year)
Walls	823,800	730	75.9	23.4
Slabs and Roofs	642,637	979	67.3	22.5
Windows and Shutters	44,856	1,171	39.9	11.5
Condensing Boilers	917	885	12.4	4.2
Biomass Plants	192	183	5.1	1.9
Heat Pumps	1,052	895	24.0	6.2
Total	1,513,454	4,843	224.6	69.7

Summary of the main interventions incentivized with Comma 344, the year 2019 (for Italy and not only for Piedmont Region) – Source: ENEA

The cost for **Vertical Walls Insulation**:
(75.9 × 1,000,000) / 823,800 = **92.13 €/m²**
The cost for **Windows Substitution**:
(39.9 × 1,000,000) / 44,856 = **889.51 €/m²**
The cost for **Roofs and Slab Insulation**:
(67.3 × 1,000,000) / 642,637 = **104.72 €/m²**

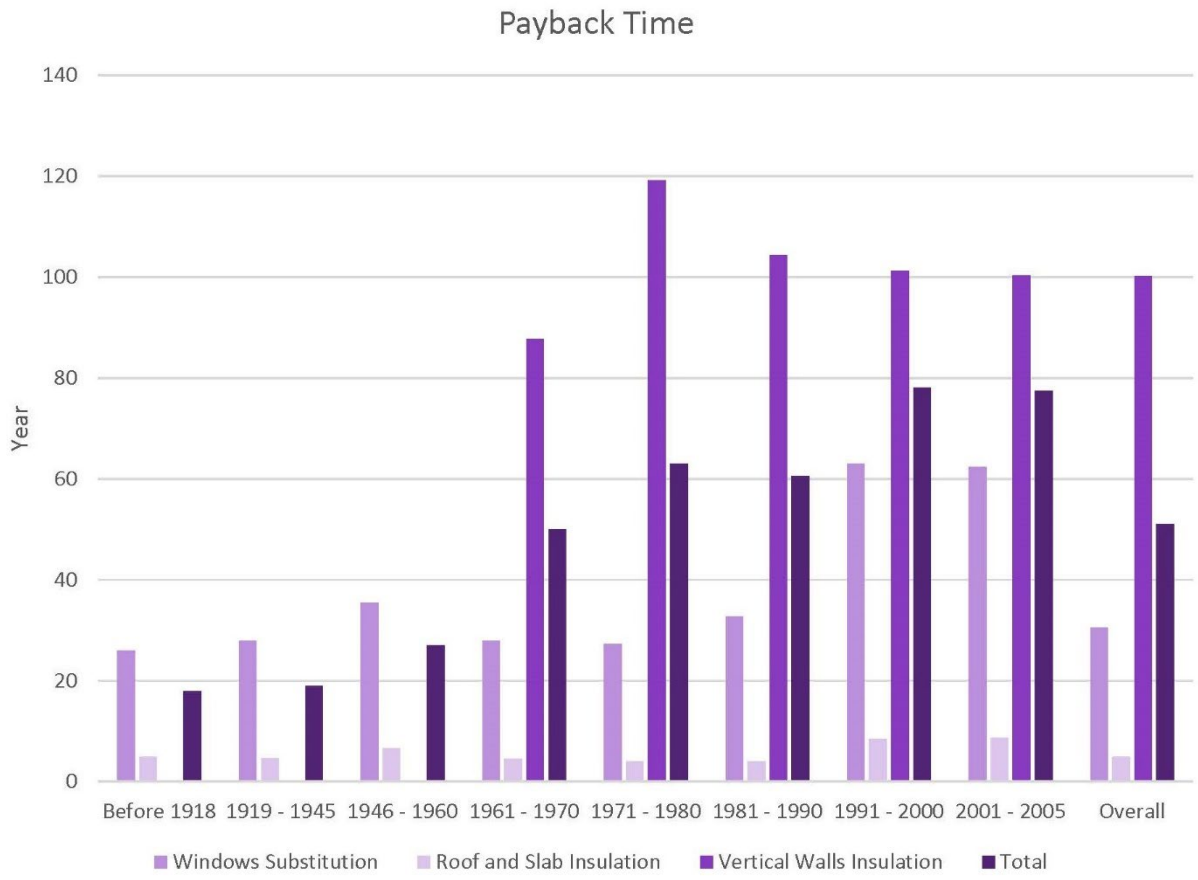
*Roof and Lower Slab Area = Building Area
*Windows Area = Useful Heated Area / 8
*Vertical Walls Area = 5.5 * Useful Heated Area

Construction Period	Cost of Interventions (€)			
	Windows Substitution	Roof and Lower Slab Insulation	Vertical Wall Insulation	Total
Before 1918	€ 2,836,131.47	€ 1,055,647.76	€ 0.00	€ 4,947,427.00
1919 - 1945	€ 15,668,905.45	€ 5,277,518.34	€ 0.00	€ 26,223,942.12
1946 - 1960	€ 77,549,340.88	€ 20,275,080.06	€ 0.00	€ 118,099,500.99
1961 - 1970	€ 114,257,105.85	€ 20,345,419.43	€ 520,696,696.71	€ 675,644,641.42
1971 - 1980	€ 92,549,050.16	€ 12,951,353.86	€ 421,768,597.21	€ 540,220,355.10
1981 - 1990	€ 31,271,355.60	€ 4,032,978.73	€ 142,511,202.98	€ 181,848,516.05
1991 - 2000	€ 15,572,527.04	€ 2,591,179.11	€ 70,967,599.88	€ 91,722,485.15
2001 - 2005	€ 5,355,206.00	€ 926,567.80	€ 24,404,956.00	€ 31,613,297.60
After 2006	€ 0.00	€ 0.00	€ 0.00	€ 0.00
Total	**€ 355,059,622.45**	**€ 67,455,745.10**	**€ 1,180,349,052.78**	**€ 1,670,320,165.43**

Payback Time Calculation

Payback Time (year) = Cost of Intervention (€) / Annual Economic Savings (€/year)

Construction Period	Payback Time (Year)			
	Windows Substitution	Roof and Lower Slab Insulation	Vertical Wall Insulation	Overall Retrofit
Before 1918	25.93	4.97	-	17.88
1919 - 1945	27.97	4.71	-	18.95
1946 - 1960	35.52	6.63	-	27.04
1961 - 1970	27.91	4.52	87.72	50.02
1971 - 1980	27.21	3.97	119.25	63.04
1981 - 1990	32.73	4.03	104.41	60.56
1991 - 2000	62.97	8.38	101.28	78.08
2001 - 2005	62.35	8.63	100.29	77.49
After 2006	-	-	-	-
Total	**30.51**	**4.97**	**100.19**	**51.09**



Conceiving Energy Retrofit Policies

Construction Period	Overall Retrofit	EC Pre (MWh/year)	EC Post (MWh/year)	R EC (MWh/year)	R ECC (€/year)	Investments Cost (€)	Average PBT (year)
Before 1918	43%	5,499.99	3,134.99	2,364.99	276,704.31	4,947,427.00	17.88
1919 - 1945	42%	28,162.07	16,334.00	11,828.07	1,383,884.25	26,223,942.12	18.95
1946 - 1960	30%	124,417.68	87,092.38	37,325.30	4,367,060.56	118,099,500.99	27.04
1961 - 1970	66%	174,935.62	59,478.11	115,457.51	13,508,528.32	675,644,641.42	50.02
1971 - 1980	63%	116,267.73	43,019.06	73,248.67	8,570,094.42	540,220,355.10	63.04
1981 - 1990	66%	38,885.99	13,221.24	25,664.75	3,002,776.06	181,848,516.05	60.56
1991 - 2005	57%	23,731.81	10,204.68	13,527.13	1,582,674.67	123,335,782.75	77.93

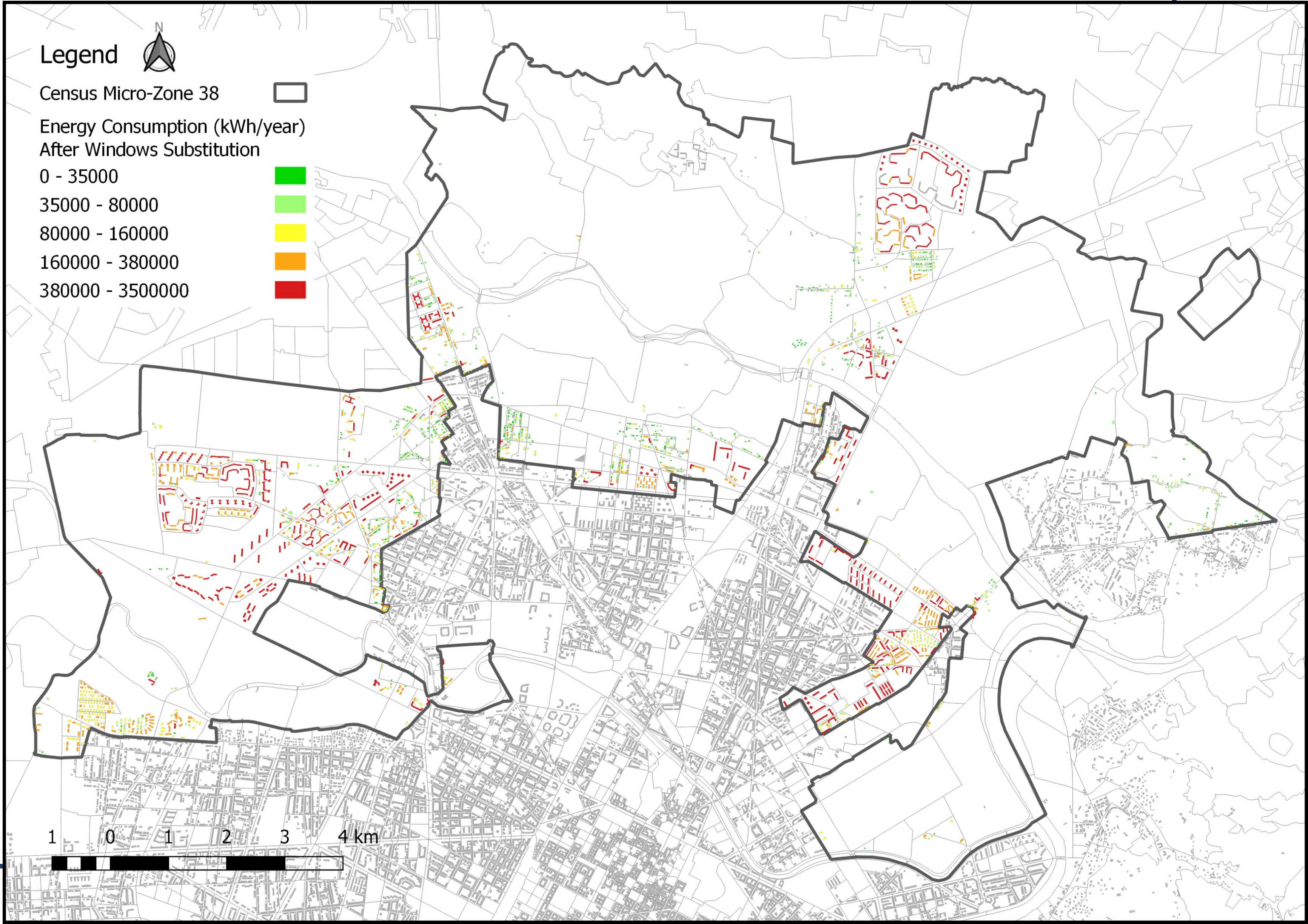
Energy Retrofit Policy Selection

*Selecting energy retrofit by effectiveness which would take excessive payback time for buildings constructed after 1961

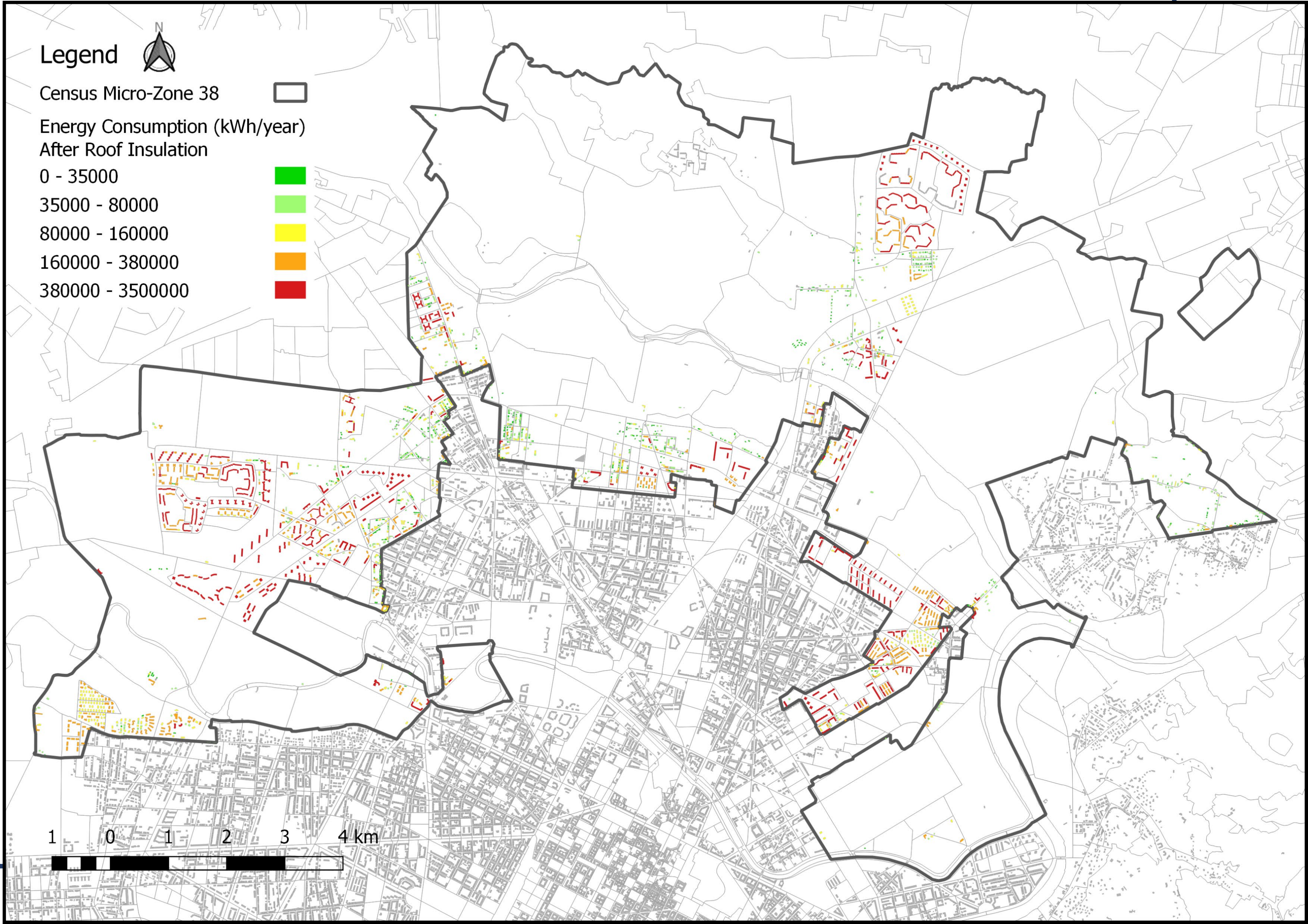
*The logical energy retrofit selection for buildings constructed after 1961 would be second effective intervention which has less payback time.

Construction Period	Intervention Type	R EC (MWh/year)	R EC (%)	Preferable Intervention (Effectiveness)	Preferable Intervention (Logical)
Before 1918	Windows Substitution	935.00	17%	Roof Insulation (24%)	
	Roof Insulation	1,320.00	24%		
	Lower Slab Insulation	495.00	9%		
	Vertical Wall Insulation	0.00	0%		
1919 - 1945	Windows Substitution	4,787.55	17%	Roof Insulation (26%)	
	Roof Insulation	7,322.14	26%		
	Lower Slab Insulation	2,252.97	8%		
	Vertical Wall Insulation	0.00	0%		
1946 - 1960	Windows Substitution	18,662.65	15%	Roof Insulation (17%)	
	Roof Insulation	21,151.01	17%		
	Lower Slab Insulation	4,976.71	4%		
	Vertical Wall Insulation	0.00	0%		
1961 - 1970	Windows Substitution	34,987.12	20%	Vertical Wall Insulation (29%)	Windows Substitution (20%)
	Roof Insulation	29,739.05	17%		
	Lower Slab Insulation	8,746.78	5%		
	Vertical Wall Insulation	50,731.33	29%		
1971 - 1980	Windows Substitution	29,066.93	25%	Vertical Wall Insulation (26%)	Windows Substitution (25%)
	Roof Insulation	16,277.48	14%		
	Lower Slab Insulation	11,626.77	10%		
	Vertical Wall Insulation	30,229.61	26%		
1981 - 1990	Windows Substitution	8,166.06	21%	Vertical Wall Insulation (30%)	Windows Substitution (21%)
	Roof Insulation	5,444.04	14%		
	Lower Slab Insulation	3,110.88	8%		
	Vertical Wall Insulation	11,665.80	30%		
1991 - 2005	Windows Substitution	2,847.82	12%	Vertical Wall Insulation (34%)	Windows Substitution (12%)
	Roof Insulation	2,373.18	10%		
	Lower Slab Insulation	1,186.59	5%		
	Vertical Wall Insulation	8,068.82	34%		

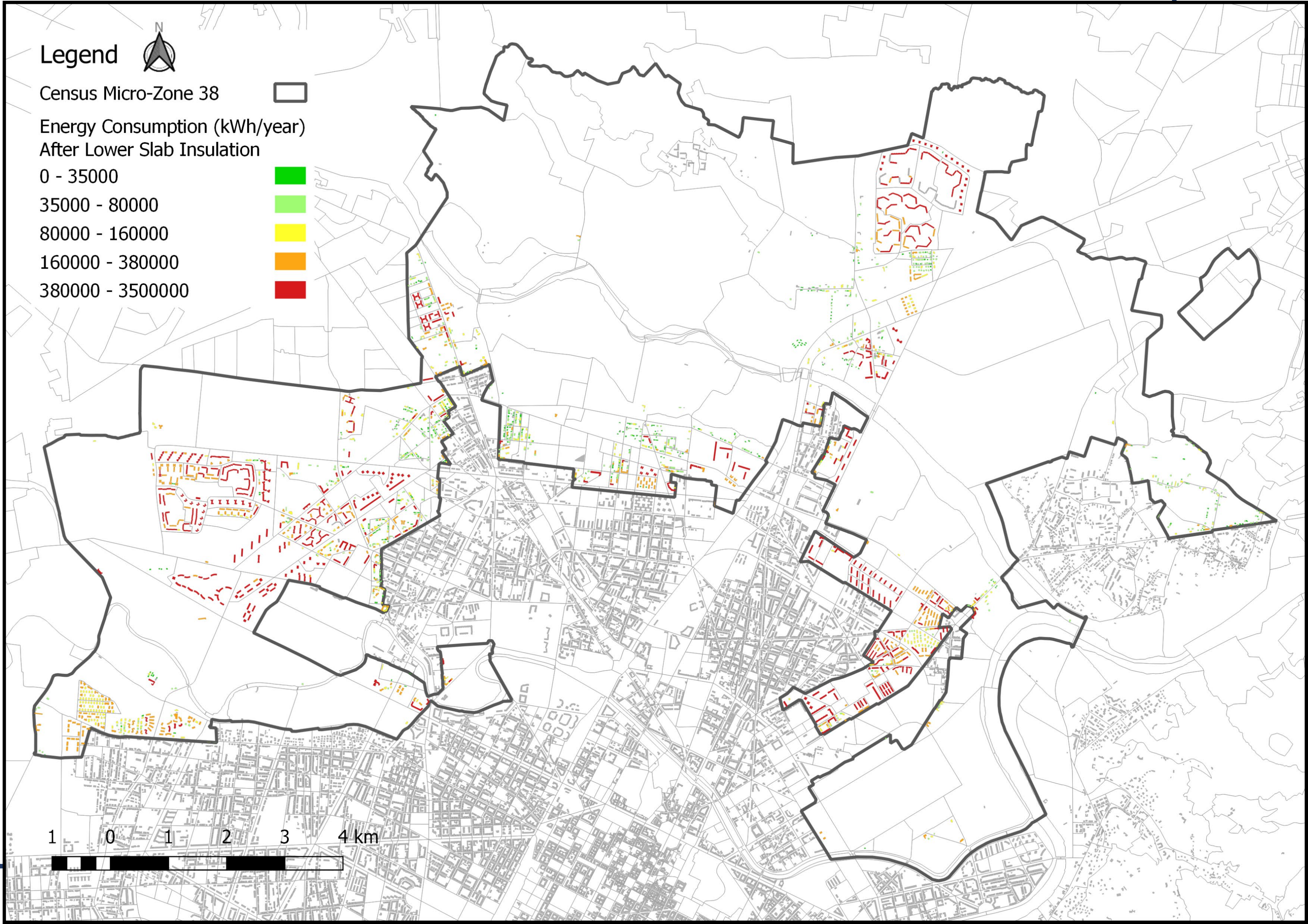
Energy Consumption After Windows Substitution



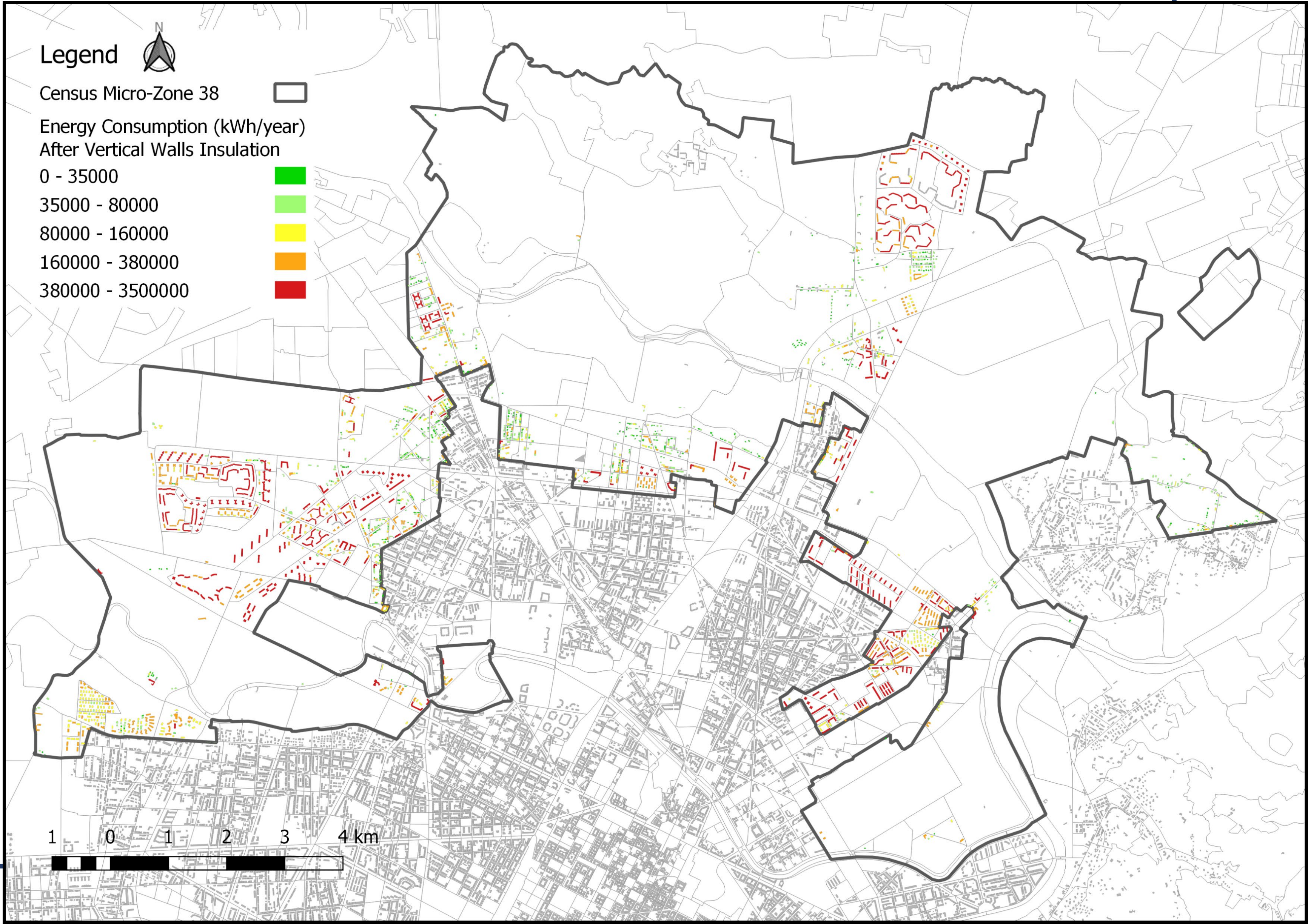
Energy Consumption After Roof Insulation



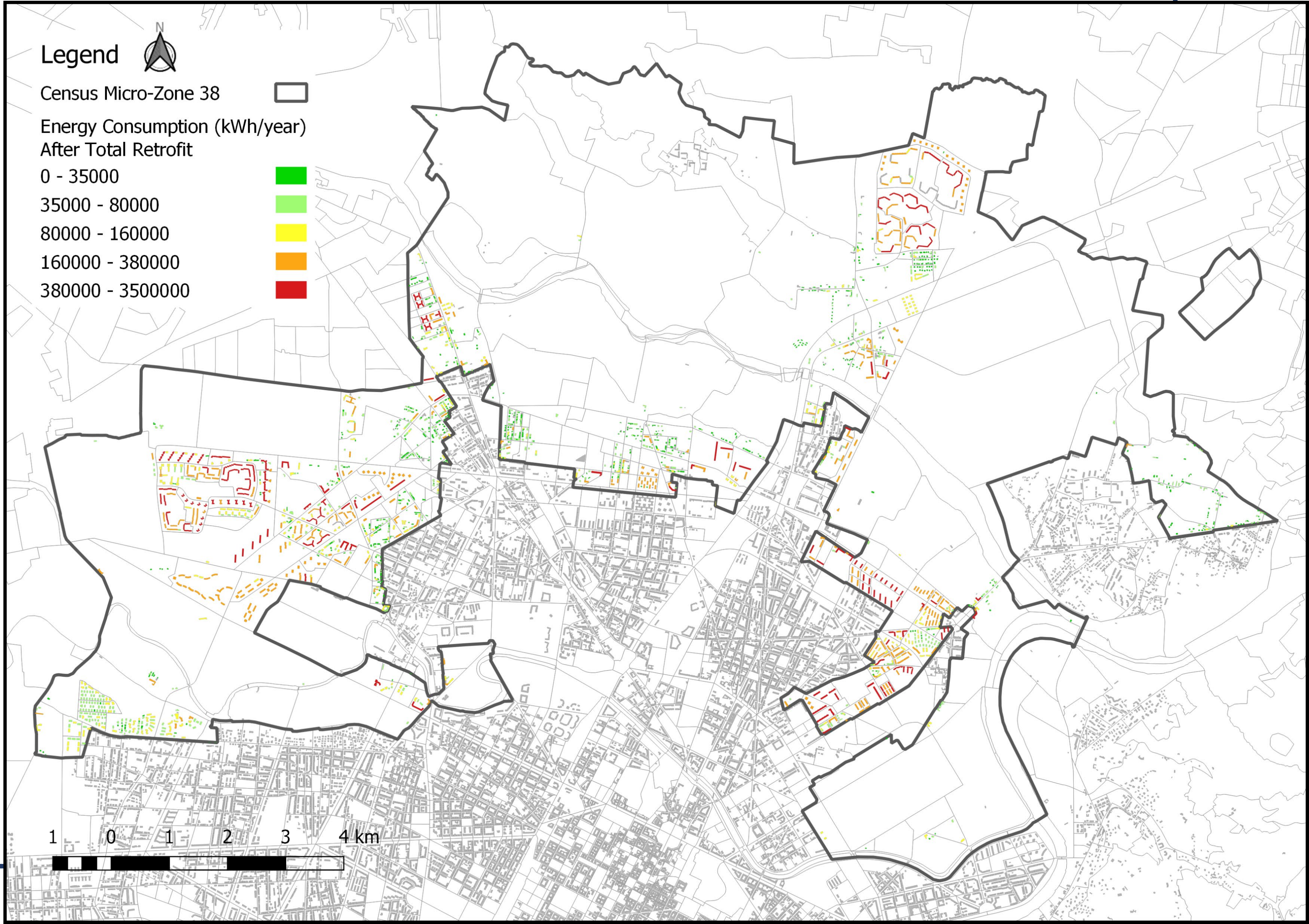
Energy Consumption After Lower Slab Insulation



Energy Consumption After Vertical Walls Insulation



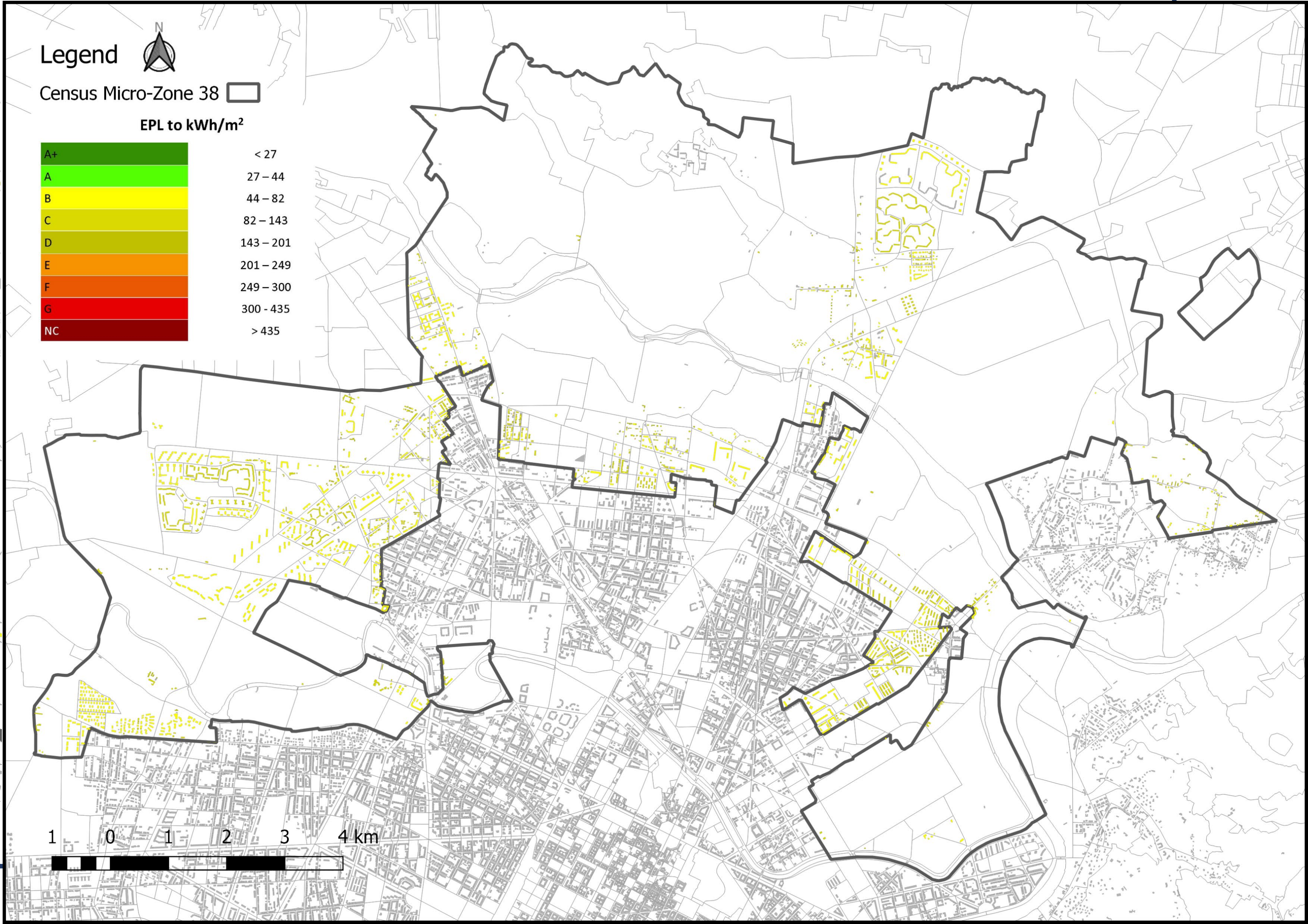
Energy Consumption After Overall Retrofit



Energy Performance After Overall Retrofit

Before

After



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Thank You
For Your Attention

Group 26

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