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Research thesis - 01VEAQA

Retrofit Challenge: Decarbonizing the Italian Residential Stock

A replicable national strategy to accelerate renovation rates, depth and investment in existing residential stock applied to the case of Italy.

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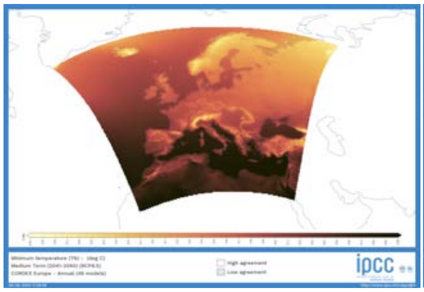
Abstract

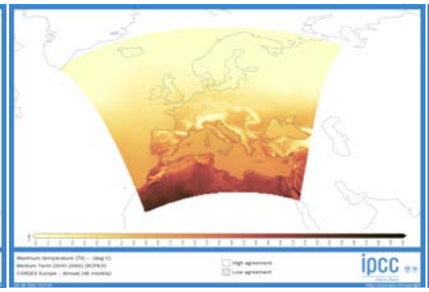
According to the IPCC and the science community in general, there is an urgent need to decarbonise the built environment in order to keep alive the possibility of achieving the goals of the Paris Agreement. Since 2015 when the targets were set, there have been different approaches and studies that show how decarbonization can be achieved, and many solutions exist nowadays to convert an existing building to net-zero and to design a new building as net-zero from the beginning. In the case of existing residential buildings, homes, the biggest problems still without solutions as of 2022, are related to accelerating the renovation rates, the depth of the renovations and solving how to incentivise the investment on retrofitting. The European Commission in October 2020, started a program called 'The renovation wave' as part of the 'European Green Deal. It, established that in Europe buildings should reduce their emissions by 55% in 2030 and become net-zero by 2050. They set three priorities on their program: energy poverty and worst performing buildings, renovation of public buildings and decarbonisation of heating and cooling. For residential buildings, the investment will in most cases fall on the home owners, and so in Italy there are different strategies already in place in terms of incentives by the Italian government, and many laws and regulations are currently being discussed to be updated in the near future. In the meantime, this research aims to create a national strategy based on the vulnerabilities that municipalities are facing, that could be replicated in other countries and focuses on tackling the three main problems mentioned: acceleration, depth and investment. Results aim to be useful for future local mitigation and adaptation action plans that need to be developed. The proposed methodology creates a comprehensible understanding of the climate projections by 2050; of the potential of small, under 5MW, solar and eolic power plants by municipality; of the stranding risk, the market value depreciation risk, that homes are facing in the country, by province; it creates an index of climate risk that rank vulnerability of all the municipalities; and explores also for each municipality, the optimal size for individual acceleration projects in order to fulfil the objective of decarbonization of the residential stock.

Section 1: Problem definition

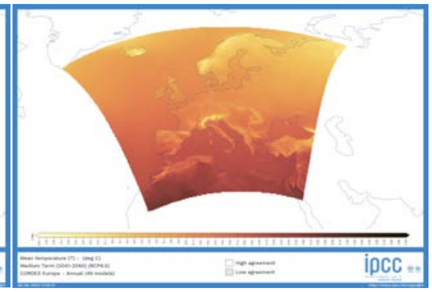
1.1.a) Climate projections



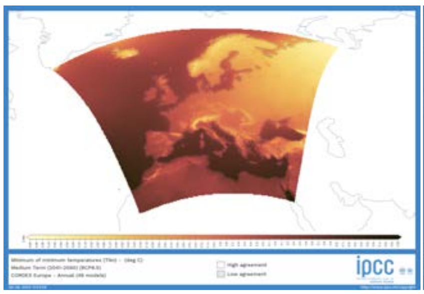
Minimum Temperature
Source: IPCC AR6 WG1, 2021d



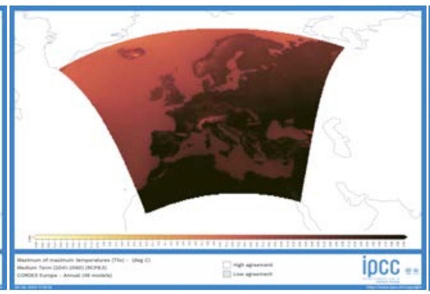
Maximum Temperature
Source: IPCC AR6 WG1, 2021e



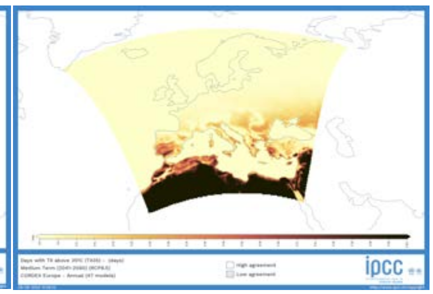
Mean Temperature
Source: IPCC AR6 WG1, 2021f



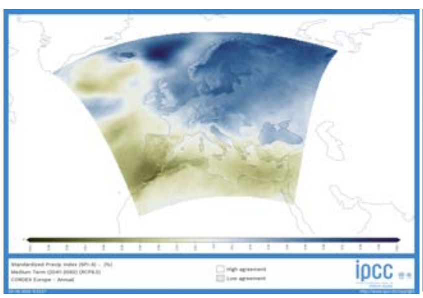
Minimum of Minimum Temp.
Source: IPCC AR6 WG1, 2021g



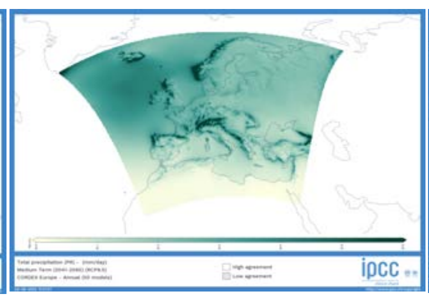
Maximum of Maximum Temp.
Source: IPCC AR6 WG1, 2021h



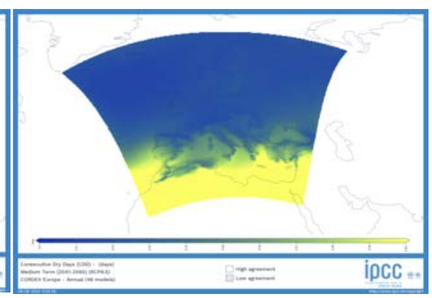
Days with T° above 35°C
Source: IPCC AR6 WG1, 2021i



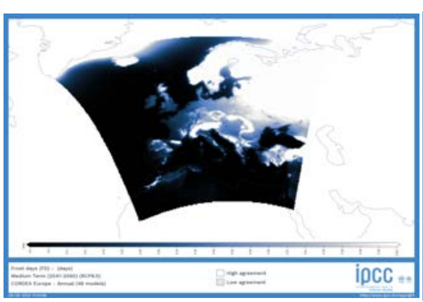
Standarized precipitation index
Source: IPCC AR6 WG1, 2021j



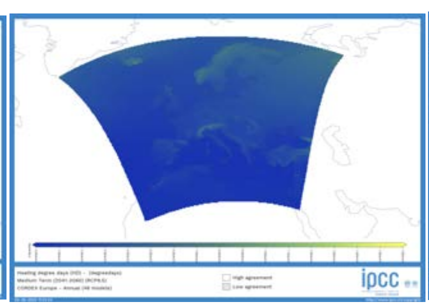
Total precipitation (mm/day)
Source: IPCC AR6 WG1, 2021k



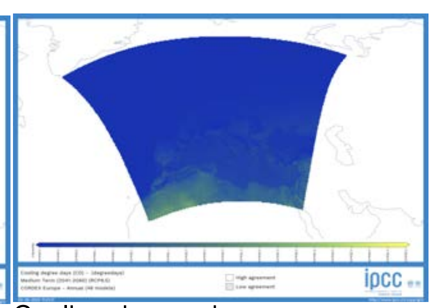
Consecutive dry days
Source: IPCC AR6 WG1, 2021l



Frost days
Source: IPCC AR6 WG1, 2021m

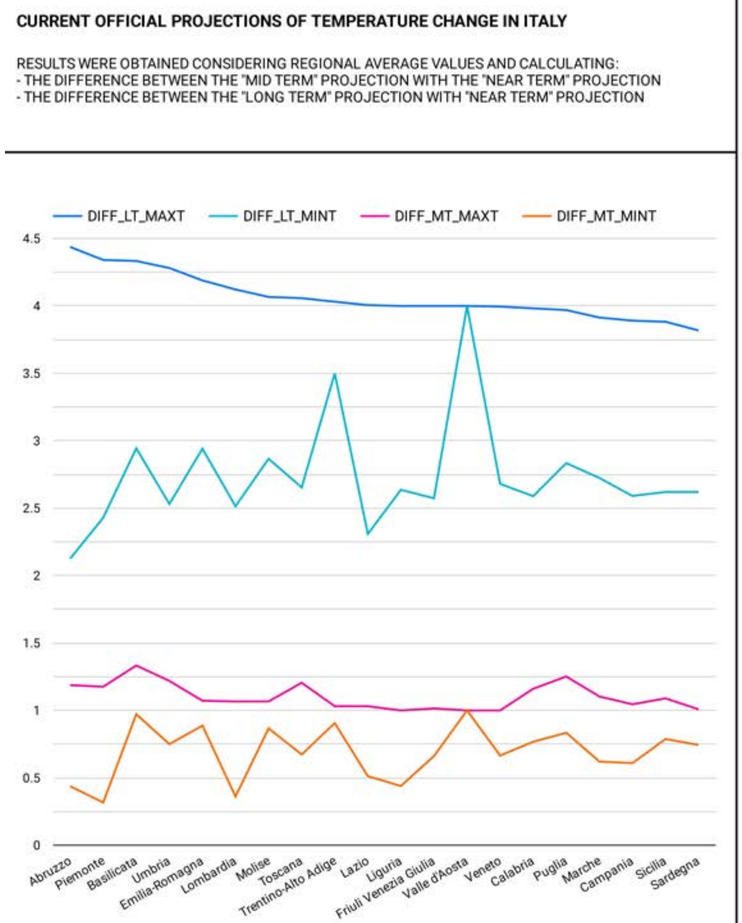


Heating degree days
Source: IPCC AR6 WG1, 2021c



Cooling degree days
Source: IPCC AR6 WG1, 2021n

According to August 9 2021 IPCC AR6 WG1 Report, CORDEX EU projection, mid-term temperature change on rcp8.5 scenario and considering 1900 temperature average as baseline, by the mid term (2040-2060), in Italy the change in the maximum temperature by region will oscillate between +4.44ºC and +3.82ºC



AVERAGE OF PROJECTED TEMPERATURE CHANGE IN ITALY (ºCelcius):

	DIFF_LT_MAXT / DIFF_MT_MAXT	DIFF_LT_MINT / DIFF_MT_MINT
LONG TERM: 2080 - 2100	4.07	2.73
MID TERM: 2040 - 2060	1.1	0.69

Abruzzo	4.44	1.19	2.13	0.44
Basilicata	4.33	1.33	2.94	0.97
Calabria	3.98	1.16	2.59	0.77
Campania	3.89	1.05	2.59	0.61
Emilia-Romagna	4.19	1.07	2.94	0.89
Friuli Venezia Giulia	4	1.01	2.57	0.66
Lazio	4.01	1.03	2.31	0.51
Liguria	4	1	2.64	0.44
Lombardia	4.12	1.07	2.51	0.36
Marche	3.91	1.1	2.72	0.62
Molise	4.07	1.07	2.87	0.87
Piemonte	4.34	1.18	2.43	0.32
Puglia	3.97	1.25	2.83	0.83
Sardegna	3.82	1.01	2.62	0.74
Sicilia	3.88	1.09	2.62	0.79
Toscana	4.06	1.21	2.65	0.67
Trentino-Alto Adige	4.03	1.03	3.5	0.91
Umbria	4.28	1.22	2.53	0.75
Valle d'Aosta	4	1	4	1
Veneto	4	1	2.68	0.67

BASED ON IPCC AR6 WG1 EU CORDEX 1900 BASELINE, RCP 8.5, AUG.2021

Current official projections of temperature in Italy
Source: Author.Based on data from (IPCC AR6 WG1, 2021b) + (IPCC AR6 WG1, 2021q)

Scenario rcp8.5 is used because as of 2022 according to scientist since 2020, is the most realistic, as numbers projected in 2014 have matched reality since 2019 as explained on the bart chart.

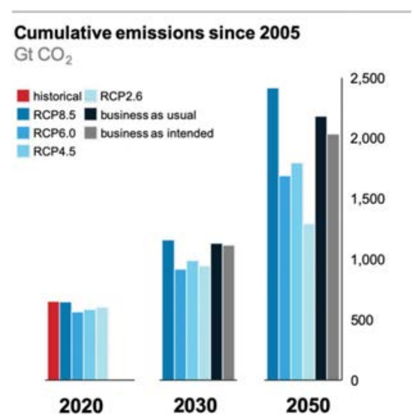


Fig. 1. Total cumulative CO_2 emissions since 2005 through 2020, 2030, and 2050. Data sources: Historical data from Global Carbon Project (6); emissions consistent with RCPs are from RCP Database Version 2.0.5 (https://tntcat.iiasa.ac.at/RcpDb/); "business as usual" and "business as intended" are from IEA Current Policies and Stated Policies scenarios, respectively (9). IEA data (fossil fuel from energy use only) was combined with future land use and industrial emissions to estimate total CO_2 emissions. Future land use emissions estimated from linear trend fit to 2005 to 2019 Global Carbon Project land use emissions data (6). Industrial emissions estimated as 10% of total emissions. Final IEA data use historical values through 2020 and scenario values thereafter. Biotic feedbacks are not included in any IEA-based estimate. Note that RCP forcing levels are intended to represent the sum of biotic feedbacks and human emissions.

Cumulative emissions since 2005
Source: Schwalm, Glendon and Duffy, 2020

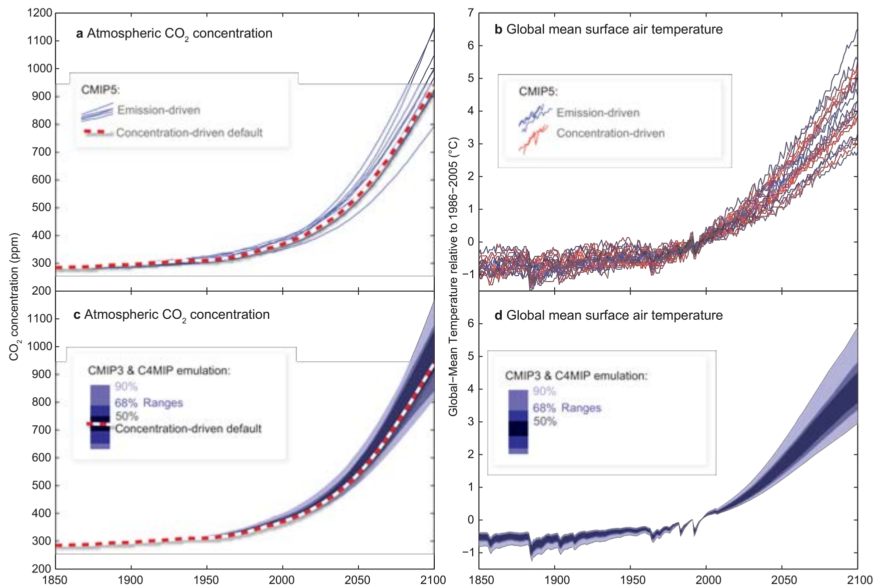


Figure 12.36 | Simulated changes in (a) atmospheric CO_2 concentration and (b) global averaged surface temperature (°C) as calculated by the CMIP5 Earth System Models (ESMs) for the RCP8.5 scenario when CO_2 emissions are prescribed to the ESMs as external forcing (blue). Also shown (b, in red) is the simulated warming from the same ESMs when directly forced by atmospheric CO_2 concentration (a, red white line). Panels (c) and (d) show the range of CO_2 concentrations and global average surface temperature change simulated by the Model for the Assessment of Greenhouse Gas-Induced Climate Change 6 (MAGICC6) simple climate model when emulating the CMIP3 models climate sensitivity range and the Coupled Climate Carbon Cycle Model Intercomparison Project (C[4]MIP) models carbon cycle feedbacks. The default line in (c) is identical to the one in (a).

IPCC 2013, Long-term Climate Change: Projections, Commitments and Irreversibility, Figure 12.36
Source: IPCC AR5 WG1, 2013

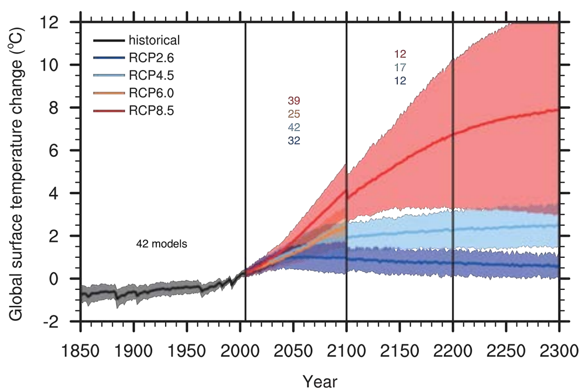
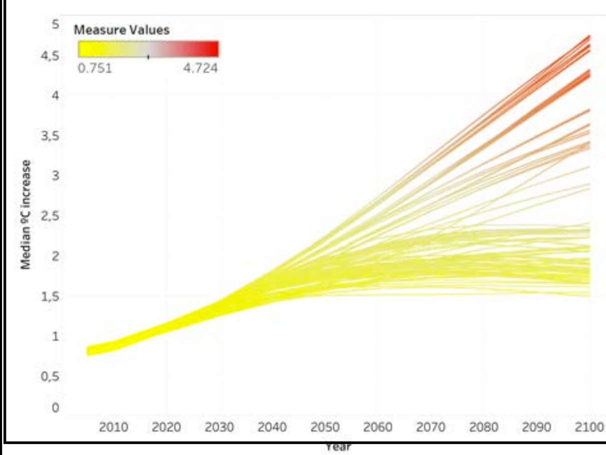


Figure 12.5 | Time series of global annual mean surface air temperature anomalies (relative to 1986–2005) from CMIP5 concentration-driven experiments. Projections are shown for each RCP for the multi-model mean (solid lines) and the 5 to 95% range (±1.64 standard deviation) across the distribution of individual models (shading). Discontinuities at 2100 are due to different numbers of models performing the extension runs beyond the 21st century and have no physical meaning. Only one ensemble member is used from each model and numbers in the figure indicate the number of different models contributing to the different time periods. No ranges are given for the RCP6.0 projections beyond 2100 as only two models are available.

IPCC 2013, Long-term Climate Change: Projections, Commitments and Irreversibility, Figure 12.36
Source: IPCC AR5 WG1, 2013



IPCC2013, World mean average temperature change in ºC, all scenarios
Source: Author. Based on data from (IPCC AR5 WG3, 2014)

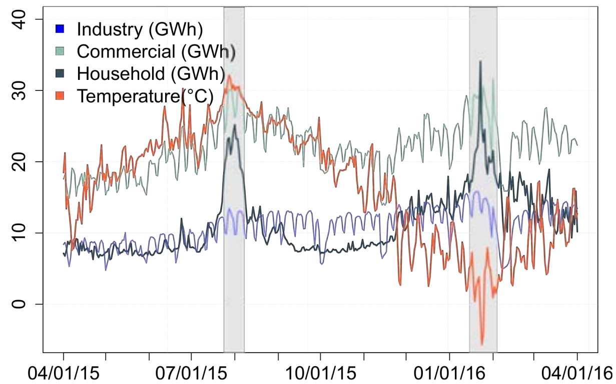


Fig. 1. Daily total electricity consumption by sector with daily temperature. The gray areas highlight the periods for extreme weather, where we see the highest response in residential electricity.

Source: Lia, Pizerb and Wu, 2018

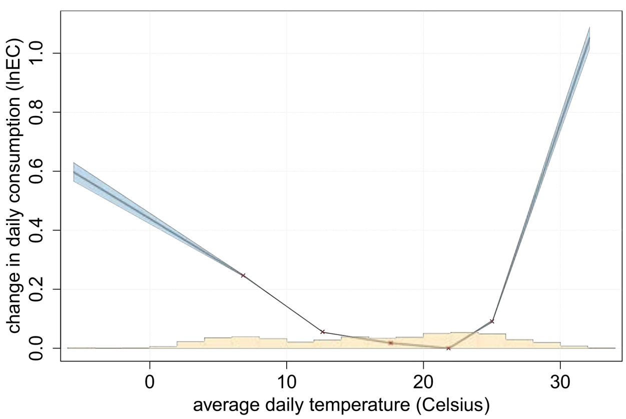


Fig. 2. The effect of temperature on daily electricity consumption. The *y* axis plots the predicted natural log of electricity consumption, *lnEC* (normalized to zero for lowest point). The light blue shading repre-

Source: Lia, Pizerb and Wu, 2018

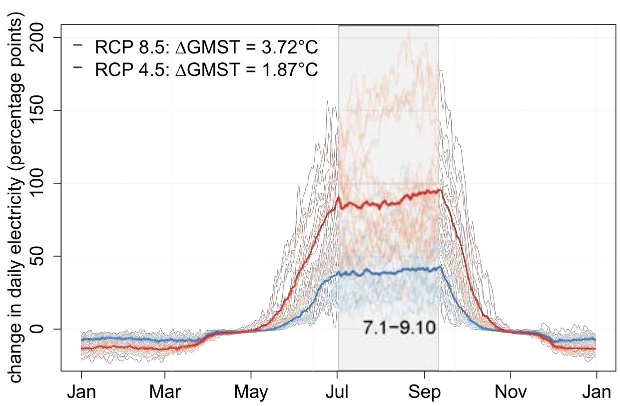


Fig. 6. Daily electricity change under climate change. Blue is RCP4.5; red is RCP8.5. Light lines show each of the 21 models individually, while the dark lines show the average. The gray area highlights the period during which the increase in daily electricity is the highest due to climate change.

Source: Lia, Pizerb and Wu, 2018

This all means that the energy consumption will also rise exponentially. Projections can be established using a variable known as Degree-days. Heat Degree Days are the ones that measure the total amount of degrees that the median of each day had, whenever it is under a baseline. If the temperature rises, HDD decrease. On the contrary Cooling Degree Days count the opposite, the same total but above the baseline therefore when temperature rises, CDD also rises.

Buildings temperature performance will become increasingly more valuable as the temperature rise, since energy consumption and therefore energy cost, will determine both, the value of the property and the quality of life of the inhabitants by the ability of heating and cooling the home. Bigger expenses on energy devaluate a property.

Considering that the world needs a 50% emissions reduction by 2030, rising energy consumption becomes a problem as the energy production's pollution is increasing the consumption, therefore it is needed to decarbonise the energy matrix.

As the Italian Government has signed the Paris Agreement, the reduction pathway for achieving the Net-Zero target by 2050 is already set, and now it is only required to organise the priority by which existing buildings will be optimised, and what acceleration measures are best for each case.

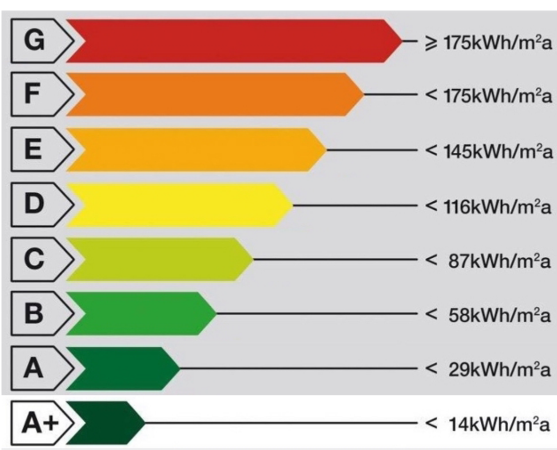
1.1.b) Paris Agreement

Italy is committed to specific pathways for reducing residential greenhouse gases emissions and energy consumption in a plan that goes from 2020 to a net-zero 2050.

PERIOD	GHG kgCO2e/sqm/yr	ENERGY KWh/sqm/yr
2020-2024	26.1 > x > 21.4	136.0 > y > 114.9
2025-2029	20.3 > x > 16.1	109.4 > y > 88.3
2030-2034	15.1 > x > 11.6	83.4 > y > 66
2035-2039	10.8 > x > 7.6	62.1 > y > 47.2
2040-2044	6.9 > x > 4.1	43.6 > y > 30
2045-2049	3.5 > x > 1.9	27.0 > y > 18.1
2050+	x < 1.6	y < 16.9

In 2019 the national average was x= 27.3 y=152.3

The Italian residential energy categorisation, assigns a category according the square meter energy consumption in the home. In order to achieve the energy targets, it means that we can know by which decade residential buildings should be of which energy categorization, in terms of energy efficiency. Also the cost considering an average of €250/mWh for final price paid by each home, PUN + Spread + transmission, etc.

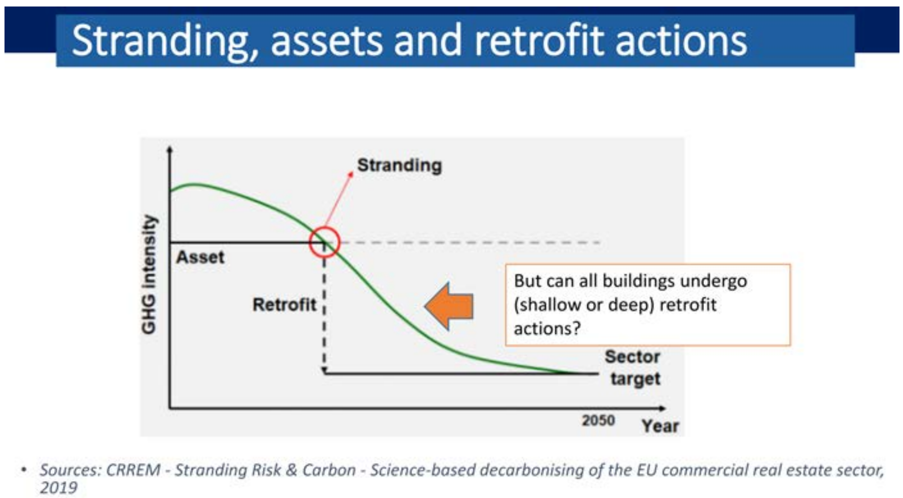


EnCat.	year	kwh/m²/yr	€/100m²/yr (€250/mWh)
F	2018	149.0	€ 136
E	2023	120.3	€ 110
D	2029	88.3	€ 81
C	2036	58.6	€ 53
B	2044	30.0	€ 27
A	2050	16.9	€ 15

Casa in classe energetica, 2022
Source: Author. Based on data from (Immaginacasa.it, 2021) + (CRREM, 2021)

1.1.c) Stranding Risk

In this context, a building becomes a stranded asset when the cost of supplying energy is bigger than the market expectations and/or the government's buildings regulations are not met. In the case of homes, the indicator is its market value. A clear example of homes that had become a stranded asset is the proliferation of €1 homes throughout Europe.



Stranding assets and retrofit actions

Source: Gabrielli et al, 2020

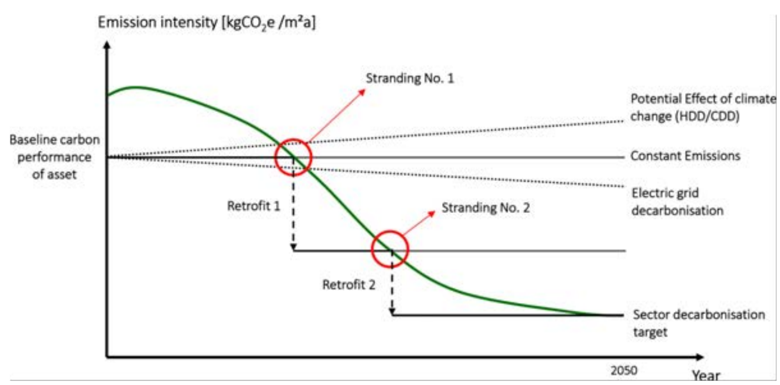


Figure 1: Stranding Diagram

'Stranding diagram': The figure above provides a summary of the fundamental principle of *CRREM's* stranding risk analysis approach for single properties:

- **Black line:** The black line represents a building's baseline and future carbon performance in terms of the so-called greenhouse gas (GHG) intensity, which is calculated as the amount of annual greenhouse gas emissions per building floor area. Emission figures include those directly generated by the on-site combustion of fossil fuels for heating and indirect emissions (caused by the use of district heating and/or electricity consumption).
- **Green curve:** The green curve represents the target decarbonisation pathway of a specific building type in a specific country that aligns with a certain climate target (1.5°C/2°C) and must not be exceeded if a property intends to be "Paris-proof". If the emission intensity is above the target value, "stranding" occurs. In that case the asset would have a carbon-footprint that is above the fair-share derived by downscaling the carbon budget to property level.

Stranding diagram

Source: CRREM, 2020, p. 5

The stranding risk is reduced with retrofit actions that accomplish decarbonisation of the energy source and/or and improve their energy efficiency. Since not all home owners can afford a deep retrofit, it is better to plan accordingly to the national targets. It is not necessary to invest 100% now in order to be inline with the targets. A better solution is invest by reaching the specific category by the specific year. Therefore distribute more efficiently the investment through the next 28 years.

For example in the case of Italy, if a house is as the national average, energy category F, there is an urgent need that a planned investment sets the property in line with the national timings defined for decarbonizing the energy consumption and improve energy efficiency.

1.2) Objective of the thesis

Provide a replicable national strategy to accelerate renovation rates, depth and investment in existing residential stock and apply it on the Italian primary homes stock.

1.3) Thesis Questions

1.3.1) Vulnerability

What is climate risk in the different parts of the country ?

According to their risk, what areas should be prioritised ?

1.3.2) Acceleration

Renovation rates: how many homes we need to group together on each action plan ?

Renovation depth means +60% in efficiency improvement: how do we achieve it ?

Private investment: how can we encourage civil society to invest in retrofitting ?

Section 2: Literature Review

2.1) Climate Projections. IPCC, Climate Change 2022: Impacts, Adaptation and Vulnerability

It is important to first acknowledge the current state of the planet, projections and recommendations, as stated on the latest IPCC report published on February 28th 2022, *Climate Change 2022: Impacts, Adaptation and Vulnerability*[1]*,* made by the *Working Group II*, *WGII*, as a contribution for the *Sixth Assessment Report for the Intergovernmental Panel on Climate Change, IPCC AR6*[2]*.* On the following tables, the column 'key points' summarise the statements quoted from the *Summary for Policymakers*[3] that will be considered further on as facts or definition for specific terms. Quotes are parts of the paragraphs and key points are provided as a way to quickly gather an idea of the latest IPCC statements.

2.1.a) SPM - Introduction[4]

SPM Paragraph	***Quote***	**Key points**
SPM.A	*how to best reduce adverse consequences for current and future generations*	The report presents solutions
	This report identifies 127 key risks	127 identified risks
	Vulnerability is widely understood to differ within communities and across societies, regions and countries, also changing through time.	Vulnerability depends on context and time
	Adaptation is subject to hard and soft limits (Hard adaptation limit - No adaptive actions are possible to avoid intolerable risks) (Soft adaptation limit - Options may exist but are currently not available)	Adaptation has limits. Hard, there is nothing to do; Soft, option is not available
	Resilience ... not just the ability to maintain essential function, identity and structure, but also the capacity for transformation.	Resilience, maintaining while being able to transform
	A common set of reference years and time periods are adopted for assessing climate change and its impacts and risks: the reference period 1850–1900 approximates pre-industrial global surface temperature, and three future reference periods cover the near-term (2021–2040), mid-term (2041–2060) and long-term (2081–2100).	Near-term = 2021-2040; Mid-term = 2041-2060; Long-term = 2081-2100
	Considering all five illustrative scenarios assessed by WGI, there is at least a greater than 50% likelihood that global warming will reach or exceed 1.5°C in the near.term, even for the very low greenhouse gas emissions scenario26	Greater than 50% likelihood that global warming will reach or exceed 1.5ºC in near term

[1] IPCC AR6 WG2, 2022a
[2] IPCC AR6 WG2, 2022a
[3] IPCC AR6 WG2, 2022b
[4] IPCC AR6 WG2, 2022b, pp 3-7

2.1.b) SPM - Observed and projected impacts and risks[5]

SPM Paragraph	Quote	Key points
SPM.B.1	*Human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability. Some development and adaptation efforts have reduced vulnerability. Across sectors and regions the most vulnerable people and systems are observed to be disproportionately affected. The rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt.*	Human-induced climate change has led to negative impacts, some of which are irreversible
SPM.B.1.1	*Increasingly since AR5, these observed impacts have been attributed to human-induced climate change particularly through increased frequency and severity of extreme events*	Negative impacts have been increasing frequency and severity
SPM.B.1.2	*The extent and magnitude of climate change impacts are larger than estimated in previous assessments ... Some losses are already irreversible, such as the first species extinctions driven by climate change ... Other impacts are approaching irreversibility such as the impacts of hydrological changes*	Negative impacts have a bigger extent than previously thought; humans are producing some irreversible changes
SPM.B.1.3	*Roughly half of the world's population currently experience severe water scarcity for at least some part of the year due to climatic and non-climatic drivers*	Water scarcity is a reality and affects around half the world population
SPM.B.1.4	*In all regions extreme heat events have resulted in human mortality and morbidity*	Extreme heat events affect humans health worldwide
SPM.B.1.5	*In urban settings, observed climate change has caused impacts on human health, livelihoods and key infrastructure ... Infrastructure, including transportation, water, sanitation and energy systems have been compromised by extreme and slow-onset events, with resulting economic losses, disruptions of services and impacts to wellbeing*	In urban settings, climate change affects human health, livelihoods and key infrastructure
SPM.B.1.6	*Some positive economic effects have been identified in regions that have benefited from lower energy demand as well as comparative advantages in agricultural markets and tourism*	Some positive effects have appeared, like lower energy demands and comparative advantages in agricultural markets and tourism
SPM.B.1.7	*Climate and weather extremes are increasingly driving displacement in all regions*	Extreme weather and climate produce displacement
SPM.B.2	*Vulnerability of ecosystems and people to climate change differs substantially among and within regions ... Approximately 3.3 to 3.6 billion people live in contexts that are highly vulnerable to climate change ... A high proportion of species is vulnerable to climate change ... Human and ecosystem vulnerability are interdependent ... Current unsustainable development patterns are increasing exposure of ecosystems and people to climate hazards*	Around 41-45% of world population is highly vulnerable to climate change. Ecosystems are also vulnerable and as they are interdependent with humans, development affect both

[5] IPCC AR6 WG2, 2022b, pp 7-20

SPM Paragraph	*Quote*	**Key points**
SPM.B.2.1	*there is increasing evidence that degradation and destruction of ecosystems by humans increases the vulnerability of people ... Unsustainable land-use and land cover change, unsustainable use of natural resources, deforestation, loss of biodiversity, pollution, and their interactions, adversely affect the capacities of ecosystems, societies, communities and individuals to adapt to climate change ... Loss of ecosystems and their services has cascading and long-term impacts on people globally*	Degradation and destruction of ecosystems increase vulnerability of humans and reduce their capacity to adapt to climate change and produce long-term impacts on people
SPM.B.2.2	*Globally, and even within protected areas, unsustainable use of natural resources, habitat fragmentation, and ecosystem damage by pollutants increase ecosystem vulnerability to climate change*	Unsustainable development increase ecosystems vulnerability to climate change
SPM.B.2.3	*Future vulnerability of ecosystems to climate change will be strongly influenced by the past, present and future development of human society*	Development of society strongly influence ecosystems
SPM.B.2.4	*and people with considerable development constraints have high vulnerability to climatic hazards*	Development constraints increase vulnerability of people
SPM.B.2.5	*Key infrastructure systems including sanitation, water, health, transport, communications and energy will be increasingly vulnerable if design standards do not account for changing climate conditions*	Design standards of key infrastructure must account changing climate conditions
SPM.B.3	*Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all*	Stabilizing global warming around 1.5ºC would reduce loss and damage to human systems and ecosystems but can't avoid all impacts
SPM.B.3.1	*If trends in urbanisation in exposed areas continue, this will exacerbate the impacts, with more challenges where energy, water and other services are constrained ... The number of people at risk from climate change and associated loss of biodiversity will progressively increase*	If trends in urbanization in exposed areas continue, impacts, people vulnerability and biodiversity loss will be progressively higher
SPM.B.3.2	*In the near term, climate-associated risks to natural and human systems depend more strongly on changes in their vulnerability and exposure than on differences in climate hazards between emissions scenarios ... Several risks can be moderated with adaptation*	In the near-term, risks are associated with vulnerability and exposure but they can be moderated with adaptation
SPM.B.3.3	*Some key risks contributing to the RFCs (reasons for concern) are projected to lead to widespread, pervasive, and potentially irreversible impacts at global warming levels of 1.5–2°C if exposure and vulnerability are high and adaptation is low*	If high exposure and low adaptation, some risks might produce irreversible impacts at 1.5-2ºC warming levels
SPM.B.4	*The magnitude and rate of climate change and associated risks depend strongly on near-term mitigation and adaptation actions*	Risks depend strongly on near-term mitigation and adaptation

SPM Paragraph	Quote	Key points
SPM.B.4.1	*Biodiversity loss, and degradation, damages to and transformation of ecosystems are already key risks for every region due to past global warming and will continue to escalate with every increment of global warming*	Worldwide, negative impacts to biodiversity and ecosystems are present and will escalate with higher warming levels
SPM.B.4.2	*Challenges for water management will be exacerbated in the near, mid and long term, depending on the magnitude, rate and regional details of future climate change*	Depending on local context water management challenges will increase in the future
SPM.B.4.3	*Global warming will progressively weaken soil health and ecosystem services such as pollination, increase pressure from pests and diseases, and reduce marine animal biomass, undermining food productivity in many regions on land and in the ocean*	As warming levels increase, soil health and ecosystem services will deteriorate more and negatively affect food production
SPM.B.4.4	*Climate change and related extreme events will significantly increase ill health and premature deaths from the near- to long-term ... Mental health challenges, including anxiety and stress, are expected to increase under further global warming in all assessed regions, particularly for children, adolescents, elderly, and those with underlying health conditions*	As warming levels increase, so will premature deaths and humans health, physical and mental, will deteriorate
SPM.B.4.5	*Climate change risks to cities, settlements and key infrastructure will rise rapidly in the mid- and long-term with further global warming*	Cities, settlements and key infrastructure risks will rise rapidly after 2050
SPM.B.4.6	*Projected estimates of global aggregate net economic damages generally increase non-linearly with global warming levels*	Economic damages will increase with warming but non-linearly
SPM.B.4.7	*At progressive levels of warming, involuntary migration from regions with high exposure and low adaptive capacity would occur*	High exposure and low adaptation will produce involuntary migration
SPM.B.5	*Multiple climate hazards will occur simultaneously, and multiple climatic and non-climatic risks will interact, resulting in compounding overall risk and risks cascading across sectors and regions. Some responses to climate change result in new impacts and risks*	Risks and hazards are not isolated within themselves and so spread around sectors and regions. New impacts and risks are produced with some responses to climate change
SPM.B.5.1	*Multiple risks interact, generating new sources of vulnerability ... These interacting impacts will increase food prices, reduce household incomes, and lead to health risks of malnutrition and climate-related mortality with no or low levels of adaptation*	Interacting impacts will directly affect people's wealth and health when no or low levels of adaptation measures
SPM.B.5.2	*In cities and settlements, climate impacts to key infrastructure are leading to losses and damages across water and food systems, and affect economic activity, with impacts extending beyond the area directly impacted by the climate hazard*	Impacts to key infrastructure in cities and settlements will spread beyond directly affected area
SPM.B.5.3	*Precipitation and water availability changes increases the risk of planned infrastructure projects, such as hydropower in some regions, having reduced productivity for food and energy sectors*	Water cycle changes affect planned water infrastructure

SPM Paragraph	Quote	Key points
SPM.B.5.4	*Risks arise from some responses that are intended to reduce the risks of climate change ... can compound climate-related risks to biodiversity, water and food security, and livelihoods*	Some climate change responses produce negative effects and increase risks
SPM.B.5.5	*Solar radiation modification would not stop atmospheric CO2 concentrations from increasing or reduce resulting ocean acidification under continued anthropogenic emissions*	Solar radiation modifications will not reduce negative impacts or CO2 concentration
SPM.B.6	*If global warming transiently exceeds 1.5°C in the coming decades or later (overshoot), then many human and natural systems will face additional severe risks, compared to remaining below 1.5°C ... some impacts will cause release of additional greenhouse gases ... and some will be irreversible*	Overshoot: exceed 1.5°C After overshoot many severe risks will appear
SPM.B.6.1	*Projected impacts are less severe with shorter duration and lower levels of overshoot*	Higher global warming produce higher impacts
SPM.B.6.2	*Risk of severe impacts increase with every additional increment of global warming during overshoot ... The resulting contribution to a potential amplification of global warming indicates that a return to a given global warming level or below would be more challenging*	Higher impacts result in potential amplification of overshoot. Higher overshoot decreases possibility of reducing warming levels

2.1.c) SPM - Adaptation measures and Enabling conditions[6]

SPM Paragraph	Quote	Key points
SPM.C	*Adaptation, in response to current climate change, is reducing climate risks and vulnerability mostly via adjustment of existing systems. Many adaptation options exist and are used to help manage projected climate change impacts, but their implementation depends upon the capacity and effectiveness of governance and decision-making processes. These and other enabling conditions can also support Climate Resilient Development*	Adaptation is adjustment of current systems to reduce risks and vulnerability. Its implementation depend on governance and decision-making processes
SPM.C.1	*Many initiatives prioritize immediate and near term climate risk reduction which reduces the opportunity for transformational adaptation*	Focus on immediate and near term risk reduce opportunity of transformational adaptation
SPM.C.1.1	*Decision support tools and climate services are increasingly being used ... Adaptation can generate multiple additional benefits such as improving agricultural productivity, innovation, health and well-being, food security, livelihood, and biodiversity conservation as well as reduction of risks and damages*	Adaptation reduce risks and damages and can generate multiple benefits to humans and biodiversity

[6] IPCC AR6 WG2, 2022b, pp 20-30

SPM Paragraph	*Quote*	**Key points**
SPM.C.1.2	*Despite progress, adaptation gaps exist between current levels of adaptation and levels needed to respond to impacts and reduce climate risks ... Most observed adaptation is fragmented, small in scale, incremental, sector-specific, designed to respond to current impacts or near-term risks, and focused more on planning rather than implementation ... At current rates of adaptation planning and implementation the adaptation gap will continue to grow*	There is a gap between adaptation implementation and needed. At current rate the gap will continue to grow
SPM.C.2	*There are feasible and effective adaptation options which can reduce risks to people and nature. ... The effectiveness of adaptation to reduce climate risk is documented for specific contexts, sectors and regions ... and will decrease with increasing warming*	Adaptation measures are identified for specific contexts, sectors and regions but their effectiveness decrease with increase of global warming
SPM.C.2.1	*Adaptation to water-related risks and impacts make up the majority of all documented adaptation ... The effectiveness of most water related adaptation options to reduce projected risks declines with increasing warming*	Most documented adaptation measures are related to water-related risks and impacts
SPM.C.2.2	*Integrated, multi-sectoral solutions that address social inequities and differentiate responses based on climate risk and local situation will enhance food security and nutrition*	Context specific solutions when multi-sectoral enhance food security and nutrition
SPM.C.2.3	*Adaptation for natural forests includes conservation, protection and restoration measures. In managed forests, adaptation options include sustainable forest management, diversifying and adjusting tree species compositions to build resilience, and managing increased risks from pests and diseases and wildfires.*	Adaptation measures in forests are specific for each type, such as natural or managed
SPM.C.2.4	*To be effective, conservation and restoration actions will increasingly need to be responsive, as appropriate, to ongoing changes at various scales, and plan for future changes*	Conservation and restoration actions must be adaptable for changes, and at all scales
SPM.C.2.5	*Ecosystem-based Adaptation is vulnerable to climate change impacts, with effectiveness declining with increasing global warming*	Ecosystem-based adaptation is vulnerable to climate change and effectiveness decline
SPM.C.2.6	*Considering climate change impacts and risks in the design and planning of urban and rural settlements and infrastructure is critical for resilience and enhancing human well-being*	For resilience and enhanced well being planning must consider climate change impacts and risks
SPM.C.2.7	*An increasing number of adaptation responses exist for urban systems, but their feasibility and effectiveness is constrained by institutional, financial, and technological access and capacity, and depends on coordinated and contextually appropriate responses across physical, natural and social infrastructure ... Globally, more financing is directed at physical infrastructure than natural and social infrastructure ... Combined ecosystem-based and structural adaptation responses are being developed*	Institutional, financial and technological access and capacity constrain adaptation responses which should be planned for local context and address physical, natural and social infrastructure

SPM Paragraph	*Quote*	**Key points**
SPM.C.2.8	*Sea level rise poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme sea level events which will escalate in the coming decades*	Sea level rise will increase frequency and magnitude of extreme events on the coasts
SPM.C.2.9	*Integrating climate adaptation into social protection programs ... is highly feasible and increases resilience to climate change*	Adaptation should be integrated with social protection programs
SPM.C.2.10	*the most feasible adaptation options support infrastructure resilience, reliable power systems and efficient water use for existing and new energy generation systems ... Energy generation diversification, including with renewable energy resources and generation that can be decentralised depending on context ... and demand side management ... can reduce vulnerabilities to climate change*	Infrastructure resilience, reliable power systems, efficient water use, energy generation diversification that can be decentralized, are feasible adaptation options that reduce vulnerability
SPM.C.2.11	*There are multiple opportunities for targeted investments and finance to protect against exposure to climate hazards ... Health and well-being would benefit from integrated adaptation approaches that mainstream health into food, livelihoods, social protection, infrastructure, water and sanitation policies requiring collaboration and coordination at all scales of governance*	Multiple opportunities for targeted investments and finance but require collaboration and coordination at all scales of governance
SPM.C.2.12	*Increasing adaptive capacities minimises the negative impacts of climate-related displacement ... Risks to peace are reduced*	Increasing adaptation reduce climate-related displacement
SPM.C.2.13	*There are a range of adaptation options ... that have broad applicability across sectors and provide greater benefits to other adaptation options when combined*	Multi-sector adaptation measures provide greater benefits
SPM.C.3	*Soft limits to some human adaptation have been reached, but can be overcome by addressing a range of constraints, primarily financial, governance, institutional and policy constraints ... Hard limits to adaptation have been reached in some ecosystems ... losses and damages will increase and additional human and natural systems will reach adaptation limits*	Solving financial, governance and policy constrains can erase soft limits to adaptation. Hard limits already exist. Adaptation limits will also appear.
SPM.C.3.1	*Lack of climate literacy at all levels and limited availability of information and data pose further constraints to adaptation planning and implementation*	Adaptation is handicapped by lack of climate literacy
SPM.C.3.2	*Financial constraints are important determinants of soft limits to adaptation across sectors and all regions ... The overwhelming majority of global tracked climate finance was targeted to mitigation while a small proportion was targeted to adaptation*	Financial constraints produce soft limits. Most climate finance target mitigation over adaptation
SPM.C.3.3	*Above 1.5°C global warming level, some ecosystem-based adaptation measures will lose their effectiveness in providing benefits to people as these ecosystems will reach hard adaptation limits*	Adaptation or not, after overshoot some ecosystems will reach hard limits
SPM.C.3.4	*Transitioning from incremental to transformational adaptation can help overcome soft adaptation limits*	Soft limits can be reduced with transformational adaptation

SPM Paragraph	*Quote*	**Key points**
SPM.C.3.5	*Adaptation does not prevent all losses and damages ... Losses and damages are unequally distributed across systems, regions and sectors and are not comprehensively addressed by current financial, governance and institutional arrangements ... With increasing global warming, losses and damages increase and become increasingly difficult to avoid*	Adaptation can't prevent all losses and damages, which are unequally distributed in the world and will be more difficult to avoid as warming level increase
SPM.C.4	*Maladaptive responses to climate change can create lock-ins of vulnerability, exposure and risks that are difficult and expensive to change ... Maladaptation can be avoided by flexible, multi-sectoral, inclusive and long-term planning and implementation of adaptation actions*	Maladaptation can generate vulnerability lock-ins, but can't be avoided with correct planning and implementation of adaptation actions
SPM.C.4.1	*Actions that focus on sectors and risks in isolation and on short-term gains often lead to maladaptation if long-term impacts of the adaptation option and long-term adaptation commitment are not taken into account ... Adaptation integrated with development reduces lock-ins and creates opportunities*	Maladaptation comes from uni-sectoral planning that doesn't consider the long-term
SPM.C.4.2	*Considering biodiversity and autonomous adaptation in long-term planning processes reduces the risk of maladaptation.*	Maladaptation risk is avoidable through good planning
SPM.C.4.3	*Adaptation planning and implementation that do not consider adverse outcomes for different groups can lead to maladaptation*	Maladaptation comes if outcomes for all groups are not considered
SPM.C.4.4	*Maladaptation is also minimized by planning that accounts for the time it takes to adapt ... the uncertainty about the rate and magnitude of climate risk ... and a wide range of potentially adverse consequences of adaptation actions*	Maladaptation can be reduced when considering timings, uncertainty, risks and consequences of actions
SPM.C.5	*Enabling conditions are key for implementing, accelerating and sustaining adaptation in human systems and ecosystems ... political commitment and follow-through, institutional frameworks, policies and instruments with clear goals and priorities, enhanced knowledge on impacts and solutions ... financial resources, monitoring and evaluation and inclusive governance processes*	Implementing, accelerating and sustaining adaptation depend on enablers, having clear goals, priorities, finance, knowledge, monitoring, evaluation and governance
SPM.C.5.1	*Political commitment and follow-through ... Implementing actions can require large upfront investments of human, financial and technological resources ... whilst some benefits could only become visible in the next decade or beyond*	Long term vision is required as some benefits will be visible in next decades
SPM.C.5.2	*clear adaptation goals and define responsibilities and commitments ... Instruments that incorporate adaptation ... strengthen adaptation actions by public and private actors*	Public and private sectors need to be aligned
SPM.C.5.3	*Enhancing knowledge on risks, impacts, and their consequences, and available adaptation options promotes societal and policy responses*	Knowledge increase societal and policy response
SPM.C.5.4	*enhanced mobilization of and access to financial resources are essential for implementation of adaptation and to reduce adaptation gaps ... accessing finance is fundamental to accelerate adaptation*	Finance is fundamental for adaptation

SPM Paragraph	Quote	Key points
SPM.C.5.5	*the monitoring of outcomes is critical for tracking the effectiveness and progress of adaptation ... facilitates learning on successful and effective adaptation measures, and signals when and where additional action may be needed*	Monitoring is fundamental for tracking progress, replicability and decide if additional action should be implemented
SPM.C.5.6	*Vulnerabilities and climate risks are often reduced through ... address context specific inequities*	Context specific inequities reduce risk and vulnerability

2.1.d) SPM - Climate resilient development[7]

SPM Paragraph	Quote	Key points
SPM.D	*Climate Resilient Development integrates adaptation measures and their enabling conditions ... with mitigation ... Pathways for advancing climate resilient development are development trajectories that successfully integrate mitigation and adaptation actions to advance sustainable development*	Action plans that integrate adaptation and mitigation measures generate climate resilient development
SPM.D.1	*climate resilient development action is more urgent than previously assessed in AR5*	Climate resilient development is urgent
SPM.D.1.1	*There is a rapidly narrowing window of opportunity to enable climate resilient development ... progressively constrained by every increment of warming*	Climate resilient development might not be possible at further warming levels
SPM.D.1.2	*Climate impacts and risks exacerbate vulnerability and social and economic inequities*	Impacts and risks increase vulnerabilities and inequities
SPM.D.1.3	*Integrated and inclusive system-oriented solutions based on equity and social and climate justice reduce risks and enable climate resilient development*	Climate resilient development require integrated and inclusive solutions
SPM.D.2	*Climate resilient development is enabled when governments, civil society and the private sector make inclusive development choices that prioritise risk reduction, equity and justice*	Prioritizing risk reduction, equity and justice on all sectors is key for climate resilient development
SPM.D.2.1	*reconcile divergent interests, values and worldviews, toward equitable and just outcomes ... Structural vulnerabilities to climate change can be reduced ... from the local to global that address inequities*	Vulnerability can be reduced with common goals and reduced inequities
SPM.D.2.2	*Inclusive governance contributes to more effective and enduring adaptation outcomes and enables climate resilient development*	Inclusive governance enables climate resilient development
SPM.D.2.3	*Governance ... is most effective when ... well-aligned across scales, sectors, policy domains and timeframes ... enabled by adequate and appropriate human and technological resources, information, capacities and finance.*	It is well known how governance can be more effective

[7] IPCC AR6 WG2, 2022b, pp 30-35

SPM Paragraph	Quote	Key points
SPM.D.3	*the global trend of urbanisation ... offers a critical opportunity in the near-term, to advance climate resilient development ... Integrated, inclusive planning and investment in everyday decision-making about urban infrastructure, including social, ecological and grey/physical infrastructures, can significantly increase the adaptive capacity of urban and rural settlements.*	Current trend of urbanization should be used as an opportunity to advance climate resilient development
SPM.D.3.1	*Taking integrated action for climate resilience to avoid climate risk requires urgent decision making for the new built environment and retrofitting existing urban design, infrastructure and land use ... Equitable partnerships between local and municipal governments, the private sector, Indigenous Peoples, local communities, and civil society*	Integrated action for climate resilience requires urgent decision making for new built environment and retrofitting the existent
SPM.D.3.2	*Urban climate resilient development is observed to be more effective if it is responsive to regional and local land use development and adaptation gaps, and addresses the underlying drivers of vulnerability*	Urban climate resilient development is more effective when vulnerabilities and land use development and adaptation gaps are addressed
SPM.D.3.3	*Urban systems are critical, interconnected sites for enabling climate resilient development, especially at the coast. ... face escalating climate compounded risks ... vital role in national economies and inland communities, global trade supply chains, cultural exchange, and centres of innovation.*	Climate resilient development is enabled when urban systems interconnected risks are considered
SPM.D.4	*Safeguarding biodiversity and ecosystems is fundamental to climate resilient development, in light of the threats climate change poses to them and their roles in adaptation and mitigation*	Climate resilient development require safeguarding biodiversity and ecosystems
SPM.D.4.1	*Building the resilience of biodiversity and supporting ecosystem integrity can maintain benefits for people*	Resilient biodiversity and ecosystems benefit people
SPM.D.4.2	*Protecting and restoring ecosystems is essential for maintaining and enhancing the resilience of the biosphere ... Climate resilient development avoids adaptation and mitigation measures that damage ecosystems*	Climate resilient development protects and restore ecosystems
SPM.D.4.3	*Biodiversity and ecosystem services have limited capacity to adapt to increasing global warming levels, which will make climate resilient development progressively harder to achieve beyond 1.5°C warming*	Climate resilient development will be harder to achieve with every increment of global warming levels
SPM.D.5	*It is unequivocal that climate change has already disrupted human and natural systems. ... Societal choices and actions implemented in the next decade determine the extent to which medium- and long-term pathways will deliver higher or lower climate resilient development ... Importantly climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline, especially if 1.5°C global warming is exceeded in the near term*	No doubt that climate change has already disrupted human and natural systems. Actions during this decade will determine the extent of further impacts in the second half of this century. Climate resilient development probably won't be achieved if overshoot happens in the near term

SPM Paragraph	Quote	Key points
SPM.D.5.1	*The prospects for climate resilient development will be further limited if global warming levels exceeds 1.5°C ... and not be possible in some regions and sub-regions if the global warming level exceeds 2°C*	Climate resilient development will be limited after overshoot, and not possible in some regions after +2ºC
SPM.D.5.2	*Experience shows that climate resilient development processes are timely, anticipatory, integrative, flexible and action focused. Common goals and social learning build adaptive capacity for climate resilient development. ... implementing adaptation and mitigation together, and taking trade-offs into account*	Climate resilient development is achieved when following the guidelines learned from previous experiences
SPM.D.5.3	*The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all.*	Climate change is a threat to human well-being and planetary health. Delay of action will compromise the possibility of a livable and sustainable future

2.1.e) Delay of action will compromise the possibility of a livable and sustainable future

Even if this report is the latest, the main message is consistent to what has been reported by the IPCC and the scientific community in general during the last decade. It's uniqueness is that it is adding new scientific proof and background for each of the statements, it has updated status on different subjects and therefore, most importantly, for the first time it is stated that the window to try to minimize climate change negative impacts is narrowing by the second. It is clear that the *overshoot*[8] will probably happen within the next couple of decades, and is also clear that unless we manage to stabilize the climate at around 1.5ºC, the second part of this century will be very challenging for human beings. Many species will go extinct and many ecosystems will be altered which would also mean that some adaptation measures that we take today, might not be effective in the future.

It is my opinion that any spatial planning project or strategy that considers the mid or long terms as time of influence, must be aligned with the common global strategies. Furthermore, during the last few years there have been thousands of persons working on identifying the problems, risks, vulnerabilities, etc. Climate change related problems are well identified and quantified. Some of them are being solved, others might be solved if the solutions are deployed on time, some others don't have a solution yet and some definitely can't be solved.

Around 40% of global greenhouse emissions are attributable to the buildings and construction sector[9], and so cities and human settlements play a major role in efforts to reduce the negative impacts of global warming. This research thesis is aligned with the current global strategies and propose an alternative to solve some specific problems that executioners are facing regarding scalability, replicability and finance in what is known as 'the retrofit challenge'. These

[8] IPCC AR6 WG2, 2022b, p. 20
[9] UNFCCC, 2021, p. 3

mentioned problems, that will be explained in detail in the following pages, are limiting the ability to deploy the solutions within the timeline set by scientists and signed by governments on the Paris Agreement commitments[10]; representing a matter that as of March 2022 doesn't have a defined solution. These specific problems were identified through the different meetings that during the two weeks of COP26[11] addressed the current sustainability issues that cities, regions and built environment stakeholders are facing. With the latest WGII IPCC report we just saw, we now have almost all the information that we need to propose a concise methodology that tries to solve these problems while being aligned with the global sustainability objectives and commitments in our sector.

2.2) A race against time. UNFCCC, Climate Action Pathways in Human Settlements

At *COP22*[12], the *Marrakech Partnership for Global Climate Action* was established to bring together the different stakeholders that are needed to achieve the *Paris Agreement*[13] commitments. These are governments, cities, regions, businesses and investors. Since 2019, the UNFCCC publishes the *Climate Action Pathways*[14], agreed by the *Marrakech Partnership*, in order to track progress and refine targets. The pathways are specific for 7 thematic areas (energy, human settlements, industry, land use, oceans and coastal zones, transport, water) and 2 cross-cutting areas (resilience, finance). Particularly important is to be familiar with these yearly updates as they present key data that should be considered in projects. In the context of this thesis, it is fundamental to be aligned with the *Human Settlements Climate Action Pathway*[15] and therefore understand the global vision and targets that relevant stakeholders have already agreed on.

The latest document, published in 2021, has set 4 milestone years in the road to achieve net-zero human settlements by 2050 (2021, 2025, 2030, 2040) with specific targets for both of the identified sub-themes that are *Built Environment* and *Waste and Consumption.* Achieving these targets in the near-term would mean that in the mid-term and long-term, cities would be healthy and resilient places where people and society will thrive, even with the harder climate conditions that they will have to live in. It is stated that *the technology solutions to transition to a net-zero built environment exist. Estimates suggest that around 70 per cent of cumulative CO2 emission reductions could be achieved from the deployment of solutions that are available today.*[16] The real problem is the pace at which solutions are being implemented. Trends show that decarbonization investments have decreased year after year since 2016, therefore making it harder to keep on the right track towards 2050.

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[10] UNFCCC COP21, 2015
[11] UNFCCC COP26, 2021a
[12] UNFCCC COP22, 2016
[13] UNFCCC COP21, 2015
[14] UNFCCC, 2019
[15] UNFCCC, 2021
[16] UNFCCC, 2021, p. 8

2.3) Retrofit Challenge. UNEP, GlobalABC, Adaptation of the building sector to climate change

The *Global Alliance for Buildings and Construction, GlobalABC*, is a partnership between different stakeholders and focused specifically on making the building sector *zero-emission, efficient and resilient*[17]. They have been providing very relevant reports in the past years, such as a yearly *Buildings Global Status Report, Buildings and Climate Change Adaptation,* and *Adaptation of the building sector to climate change: 10 principles for effective action*[18] within many others. The latest was published on March 6, 2022 and summarize the 10 principles that were discussed on the panels at *COP26*[19] and later agreed within stakeholders, and as reassuring commitment from the building sector in response to the February 28th, 2022 IPCC report *Climate Change 2022.*

These principles are the following (on columns, principle is the name, quote a part of the actual text, key points according to my view):

Principle	*Quote*	Key points
1: Urgency	*Safety and continuity of service in a context of climate change are essential ... Define a climate adaptation action plan for buildings*	Every building, new and already constructed must have an adaptation action plan
2: Stakeholders	*all should take coordinated actions ... Engage all stakeholders in a long-term vision that fosters inter-disciplinary and cross-sector collaboration.*	All stakeholders must work towards the same objectives
3: Process	*understanding of risk and a commitment to continually improve resilience ... It needs to be interconnected with disaster management ... comprehensive life-cycle assessment processes ... integrate adaptation at all stages of the building lifecycle*	Adaptation plans must consider all life cycle of the building, from the project to demolition/dismantling and not only operation
4: Mitigation	*globally buildings generate 39 per cent of world's greenhouse gas emissions ... more mitigation means less adaptation. ... Adaptation and mitigation need to be pursued actively and simultaneously ... Action in buildings sector must be a center-piece for both improving resilience and reducing GHG emissions.*	More mitigation = less adaptation and therefore both must be considered on the action plans
5: Data	*physical climate risk analyses is driving a market for geo-specific physical climate risk data. ... Those seeking to employ forward-looking climate risk data in the service of adaptive planning need to learn about, understand, and critically use such data taking into account uncertainty.*	Climate projections are uncertain and therefore action plans must be adaptive in the future if reality surpass the estimates

[17] UNEP GlobalABC, 2015
[18] UNEP GlobalABC, 2022a
[19] UNFCCC COP26, 2021b

Principle	*Quote*	Key points
6: Scale	*Buildings and urban services are interdependent, and improving the resilience of both is essential. Building resilience is highly related to full integration to city- and community-level resilience ... adaptation action should be designed at the most suitable scale (building, bloc, city).*	Action plans should consider the building surroundings, context, and already present action plans at other scales (from regional to bloc)
7: Green	*Many design and development practices are exacerbating climate risk rather than minimising it ... Nature-based solutions can help address most of upcoming climate impacts ... promote nature-based solutions from building to city scale*	Nature-based solutions are the best ones, but only if implemented correctly as if not they produce misadaptation
8: People	*A more resilient built environment must address this deficit of quality, resilient and affordable housing ... given the scale of the affordable housing deficit, solutions must be aligned with net-zero mitigation pathways ... support and protect populations and workers of the building sector that are most vulnerable*	Action plans shouldn't in any way compromise affordability, as it is also one big challenge the one of protecting the most vulnerable
9: Finance	*short-term payback periods in real estate markets works against anticipating and addressing long-term climate risks, and doing so negatively affects the resilience of local populations ... finance initiatives should promptly only be allocated to buildings projects integrating adaptation measures ... analyse localised climate risk data in their portfolios and improve their approach to financing adaptation*	Without finance, action plans can't be implemented. Most buildings on our planet are economic investments and combining long term challenges with economic returns/loss is a key issue
10: Local	*Adaptation measures are by nature location specific and should be designed locally to guaranty effectiveness. ... An adaptation plan developed at local scale based on local knowledge and building practices should be implemented at the first stage of the project and followed and adapted during the whole life cycle of the building.*	Action plans must be localized and specific for each context as there are vulnerabilities and risks vary from place to place

The building sector has many stakeholders: *national governments, local authorities, academics, investors and assets managers, insurers and re-insurers, property and project developers, architects, engineering companies, material and equipment producers and utility companies, regulation and normalisation actors, building owners and occupants, etc.*[20] It is evident that coordinating stakeholders is a challenge by itself. Since *COP21*, the last 7 years of negotiations has produced clear pathways, guidelines, principles, etc, that can't just be ignored as as stated, it is imperative that there must be alignment while going forward towards the *Paris Agreement* commitments. *However, staying under a +1.5°C global temperature increase is no longer possible, as the objective to reach near-zero energy in new construction was not reached by 2020. At present, staying under 2°C is still achievable, but the longer the sector waits to make a transition the more abrupt this transition will have to be.*[21]

[20] UNEP GlobalABC, 2022b
[21] UNEP GlobalABC, 2021a, p.10

In order for the building sector to achieve the committed greenhouse reductions for becoming net-zero by 2050, there are two main challenges: a) New constructions; b) Retrofit existing stock. *Around 40 per cent of buildings and 75 per cent of infrastructure that are predicted to exist in 2050 have yet to be built, and the built assets that already exist require retrofit to bring them to net-zero standards.*[22] For both challenges we need governance to scale up but also commitment by all other stakeholders. The retrofit challenge accounts for around 60% of the buildings that will exist in 2050 and as these buildings already exist today, it is a major challenge as we need to transform the existing building stock to be in line with the required efficiency standards. It is a far more complex problem than achieving net-zero on new buildings, as for that we would basically just need stronger regulations and their enforcement.

In the European Union, the retrofit challenge comprise *more than 220 million buildings units, representing 85% of the EU building stock*[23]*.* Considering the fact that to keep in line to the *Paris Agreement*, in Europe alone there must be, in building renovations, an investment of €3.5 trillions by 2030, which will affect 35 million buildings[24] and so €100.000 per building unit as a rough estimate: it is very clear that public finance can't achieve the retrofit challenge by itself, as the EU retrofit challenge will cost, roughly, €22 trillions by 2050. It can be infinitely discussed what is the best way to invest public finance in order to help the retrofit challenge, but there is no doubt to anyone that the vast majority of the transition of the built environment to net-zero will be financed by private investment. In Europe, the gap between public investment and needed investment is around €275bn per year: *The Next Generation EU (NGEU) fund of €750bn, active until 2026, is the EU's mechanism to finance recovery and kickstart the Green Deal ... EU leaders have also agreed that one third of the 37% - €83bn over 5 years - should support building renovations ... this is the largest climate investment gap in any of the sectors the Green Deal is focused on.*[25]

In this context, the 'World Business Council for Sustainable Development' has become one of the most important non government organizations focused on accelerating sustainability and therefore their guidelines are the ones that are most followed across the private sector.[26] As the retrofit challenge needs to be mostly financed by the private sector, it is very relevant in the context of this research, to acknowledge what are, for the most influential coalition of private businesses advocating for sustainable development, the pathways going forward.

2.4) Resilient Neighborhoods. WBCSD, Vision 2050: Time to Transform

The first lines of the *WBCSD Vision 2050: Time to transform* say it all: *If you are reading this report with the idea that tomorrow is going to be much the same as today, then this is not for you. This is a report for change, urgent change even, starting now.* [27]

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22 UNFCCC, 2021, p. 3
23 European Commission, 2020
24 Green Finance Institute, 2021
25 Green Finance Institute, 2021
26 WBCSD, 1995
27 WBCSD, 2021, p. 1

The vision is*: 9+ billion people living well, within planetary boundaries, by 2050.*[28] *"Living well" means that everyone's dignity and rights are respected, basic needs are met, and equal opportunities are available for all. Living "within planetary boundaries" means that global warming is stabilized at no more than +1.5°C, and nature is protected, restored and used sustainably. It also means that societies have developed sufficient adaptive capacity to build and maintain resilience in a healthy and regenerative Earth system.*[29] *Business plays a central role in delivering the products and services that societies need, including: energy; transportation & mobility; living spaces; products & materials; financial products & services; connectivity; health & wellbeing; water & sanitation; and food. For each of these areas, we have outlined an ambitious yet plausible vision and pathway for transformation.*[30] *We recognize that the pathways are highly interlinked, and that none can be considered in isolation.*[31] *It is not enough to know what needs to be done. We need to accept that radical shifts in all parts of society will be required, including business. Mindset shift 1: REINVENTION. Reinvention means recognizing that our current system of capitalism is producing outcomes that are unsustainable. Generating long-term returns requires a transformed model of capitalism that rewards true value creation, rather than value extraction. Mindset shift 2: RESILIENCE. Resilience means enhancing business' capacity to anticipate, embrace, and adapt to changes and disruptions in order to safeguard its long-term success. Mindset shift 3: REGENERATION. Regeneration means moving beyond a "doing no harm" mindset to one in which we build the capacity of our social and environmental systems to heal and thrive.*[32] *Business no longer has time to wait for the stars to align – for the right regulations, the right market conditions, the right innovations to fall into place.*[33] *Delaying action makes achieving Vision 2050 impossible, and guarantees pain, suffering and even collapse – socially, environmentally, economically.*[34] *The leadership that we need to drive these transformations will be based on three core elements of this updated vision.* (1) *SHARED VISION. Business leads by unequivocally recognizing the urgent need for change, upholding the facts underpinning this urgency, and by being open and realistic about the necessary transformations that lie ahead.* (2) *SYSTEMS THINKING. Systems thinking will be at the heart of progress toward our vision. It will open business leaders' eyes to the macrotrends, disruptions and innovations that shape the world they operate in; to risks to future resilience and profits; and to their dependence on the stability and success of other industries and institutions, communities and ecosystems.* (3) *MINDSET SHIFTS. These mindset shifts – reinvention, resilience and regeneration – will not only make the pursuit of the transitions in our pathways inevitable, they will reinforce the importance of systems perspectives and our shared vision.*[35]

[28] WBCSD, 2021, p. 1
[29] WBCSD, 2021, p. 7
[30] WBCSD, 2021, p. 8
[31] WBCSD, 2021, p. 24
[32] WBCSD, 2021, p. 81
[33] WBCSD, 2021, p. 89
[34] WBCSD, 2021, p. 110
[35] WBCSD, 2021, p. 111

The three core elements for businesses - shared vision, system thinking, mindset shift - are not only completely aligned to what we have seen so far, but also provides us with an interesting approach for proposing solutions. The retrofit challenge is directly addressed on six of the nine pathways: energy, living spaces, products & materials, financial products & services, health & wellbeing, water & sanitation.

A key direct contribution to this research, is from the *2050 Vision For Living Spaces*[36], specifically in terms of identifying 7 *Key Transitions*, all of them which are absolutely important, but according to my point of view, one above all: *THE EMERGENCE OF RESILIENT URBAN AND RURAL COMMUNITIES. Long-term resilience is integrated into urban and rural infrastructure and planning, with planners enhancing their capacities to adapt, learn and transform. / Cities and local authorities lead societies in adapting to major climatological changes and embracing resilience. This includes resilience to extreme weather events, changing sea levels, water scarcity, increased temperature, lower agricultural harvests and fewer material resources. / Buildings' capacity to manage storm-surge flooding and heat waves is enhanced. Water is collected and diverted to new uses, green spaces are used to reduce drought, and technological advancements support heat regulation and healthy indoor climates. / Cities and communities foster resilience to other potential environmental and social shocks, including pandemics. / Universally accessible early warning systems and emergency planning are put in place globally. Urban and rural inhabitants are well-prepared to roll out emergency protocols.*[37]

If we take into consideration what we saw earlier, and specifically the 'Principle #10, Local' proposed by UNEP, GlobalABC, we understand that each local context is different and therefore action plans should be location specific in order to address their own risks. But, as very well pointed out by the WBCSD, a key transition is to build resilience.

In order to create resilient neighbourhoods, in such a way that it can be applied in any context - urban, suburban, rural - there is missing an updated risk analysis that can provide new data such as timings, costs, gains, risks if not achieved, etc. This data can then help to prioritize interventions, in order to achieve the retrofit challenge and reduce risks.

2.5) Decarbonization. ETC, Keeping 1,5ºC Alive

Global warming is caused mainly by three different types of gases: carbon dioxide, nitrous oxide, methane. As the *ETC*[38] very clearly explained the summarized data at COP26, Methane gases are produced by fuel production, waste management and AFOLU - agriculture, forestry and other land use - which is also the main responsible of production of nitrous oxide gases. In 2019, buildings produced around 5% of total nitrous oxide gases (0,2 of the 4 Gt CO2e

36 WBCSD, 2021, pp. 38-43
37 WBCSD, 2021, p. 41
38 Energy Transitions Commission, 2016

released in the air per year). Buildings, also in 2019, accounted for releasing into the air 9,6 Gigatons of CO2. The total amount of CO2 that humans released into the air in 2019 was 39,6 Gt CO2, which means that buildings accounted for 24,5% of total CO2. It is estimated that the amount of CO2 released to the air in the year 2030, if we continue 'business as usual', will be around 43 Gt CO2. In order to be aligned with the *Paris Agreement* commitments, and the scientific information provided by the IPCC, the release of CO2 in 2030, can't be more than 21 Gt CO2. This means that in the next 7 years our annual production of CO2 must become less than half of what it is today. This reduction should continue to decrease up to 2050, where we should be producing globally less than 5 Gt CO2 in order to achieve the net-zero by 2050 goal.[39] After COP26, the current sum of governments commitments accounts for a global total reduction of 9,5 Gt CO2 (less than 43,2% of the needed 22 Gt CO2 reduction in yearly production) by 2030, meaning there is a gap of 12,5 Gt CO2 between what governments promised to reduce by 2030 and what is needed to be reduced by 2030.[40] But there is still hope, as the *Mission Possible Partnership* representing seven of the most polluting sectors, around 60% of total CO2 - aluminium, concrete/cement, chemicals, steel, aviation, shipping, trucking - is steadily working and leading the way towards net-zero by 2050.[41] On March 2022, and as a response to the February 28th IPCC report, the *ETC*, which is also a member of the *Mission Possible Partnership,* published a new report in the *Keeping 1.5ºC Alive series* which is called *Mind the gap: How Carbon Dioxide Removals Must Complement Deep Decarbonisation to Keep 1.5°C Alive*[42] which, as its title says, explains that according to the new official information provided by the IPCC in February 2022, the *CDRs*[43] are now indispensable in order to achieve net-zero by 2050. This because according to the IPCC, in order to keep the *Paris Agreement,* the world has a budget of 500 Gt CO2 that can be released in the air between 2020 and 2050. But even with the successful implementation of *the most ambitious decarbonization scenarios* currently being worked on, we will still release into the air between 570-725 Gt CO2 by 2050. This means that we will need not only to achieve all the current commitments and plans that are in place, but also we will need to directly remove from the atmosphere a net amount of 70-225 Gt CO2 between 2020 and 2050 if we want to keep the possibility open to achieve the *Paris Agreement* commitments. They propose a very comprehensive action plan in order to keep alive these commitments, which as they say is still technically possible but only if we start implementing CDRs.[44] This research thesis is not about wether the *Paris Agreement* is feasible to be achieved or not. It is about proposing a methodology for accelerating and scaling up the deployment of solutions needed to guarantee that the commitments made by the building sector to become net-zero by 2050, will be accomplished. If they are, not only they will contribute to the possible achievement of the *Paris Agreement,* but will also provide a better quality of life for the people inhabiting the planet in the second half of this century.

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[39] Energy Transitions Commission, 2021a
[40] Energy Transitions Commission, 2021b
[41] Mission Possible Partnership, 2021
[42] Energy Transitions Commission, 2022
[43] IPCC, 2018
[44] Energy Transitions Commission, 2022

A 'net zero building sector' has a different meaning according to the organization we take as reference. For the global leaders of the sector, the *UNFCCC*[45], the *WBSCD*[46] and the *UNEP, GlobalABC*[47] being net zero means to address the whole-life carbon of the buildings and not only the operation. This approach includes the *Gray Energy* which is the greenhouse gases produced for creating the construction materials and therefore embodied in the building. Basically according to this ideology in order to be 'net-zero', a building's whole value chain must be net-zero, from the production of the materials to the final demolition or re-use of these materials, obviously through the operation and other stages of a building life cycle. This is a view that has emerged in the last few years, and is widely accepted as the meaning of 'net-zero building sector'. In order to become net-zero, the building sector need to implement a different types of measures.

The *GlobalABC* has identified eight key themes that are required in order to achieve a net-zero, efficient and resilient building sector: *1) urban planning - Prioritise integration in rapidly expanding cities. Integrate energy efficiency in urban planing policies, develop national and local urban plans and ensure collaboration among national and subnational levels and across themes - 2) new buildings - Prioritise high efficiency standards. Develop decarbonisation strategies, implement mandatory building energy codes, incentivise high performance - 3) existing buildings - Accelerate action on building retrofits. Develop and implement decarbonisation strategies for refurbishment and retrofit, increase renovation rates and depth, encourage investment - 4) Building operations - Facilitate maintenance and building management. Sustained adoption of energy performance tools, systems and standards enabling evaluation, monitoring, energy management and improved operations - 5) Appliances and systems - Stimulate demand for energy efficient appliances. Further develop, enforce and strengthen minimum energy performance requirements, prioritise energy efficiency in public procurement - 6) Materials - Promote the use of low carbon materials. Develop embodied carbon databases, raise awareness and promote material efficiency, accelerate efficiency in manufacturing to reduce embodied carbon over whole life cycle - 7) Resilience - Build-in resilience for buildings and communities. Develop integrated risk assessment and resilience strategies to ensure adaptation of existing buildings and integrate resilience into new construction - 8) Clean energy - Accelerate the decarbonisation of electricity and heat. Develop clear regulatory frameworks, provide adequate financial incentives, encourage on-site renewable energy or green power procurement, accelerate access to electricity and clean cooking.*[48]

In the context of this research, it is also very relevant to understand what does it mean for a building to be zero carbon.

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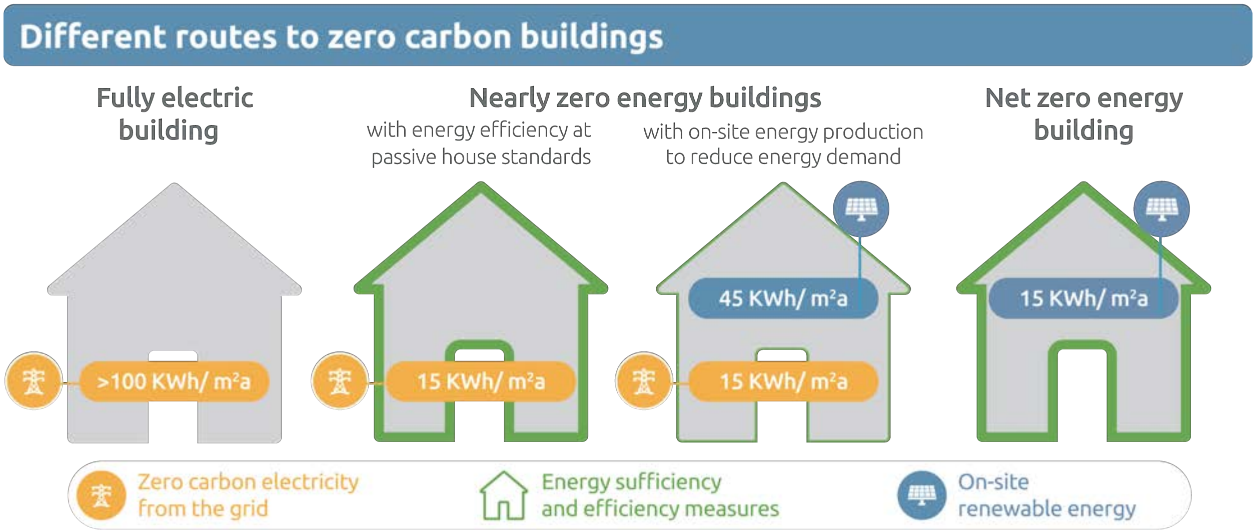
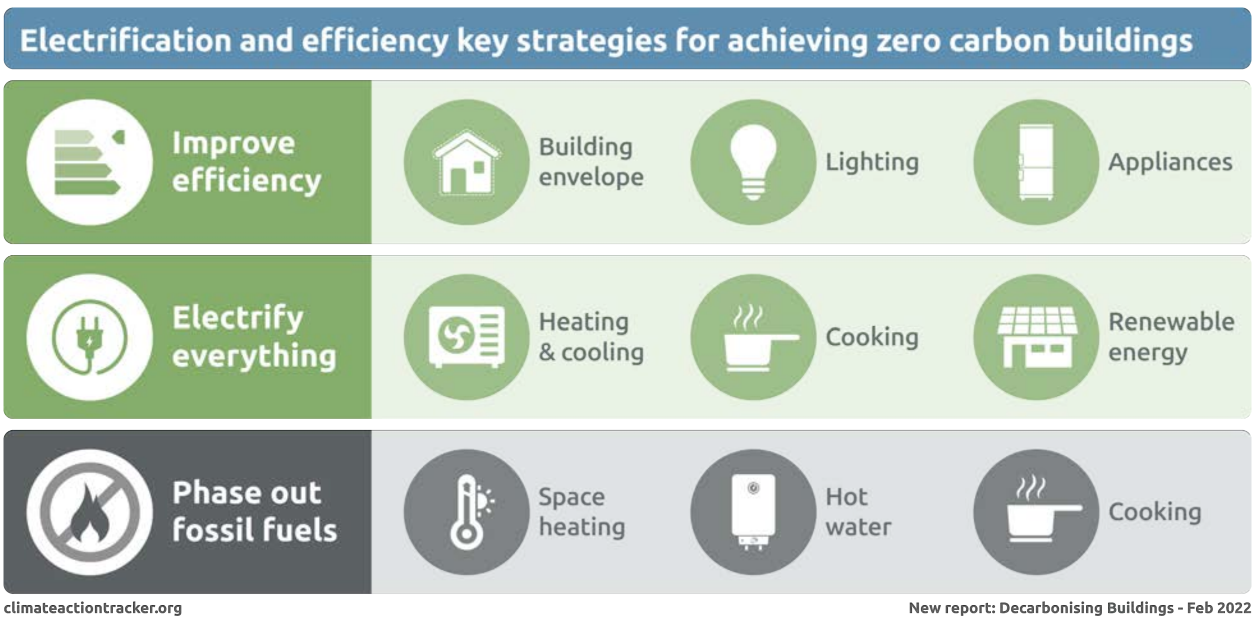
45 UNFCCC, 2021, p. 3
46 WBCSD, 2020
47 UNEP GlobalABC, 2020
48 UNEP GlobalABC, 2020



Source: Climate Action Tracker, 2022



Source: Climate Action Tracker, 2022

As the *CAT* images explain, *there are different routes to zero carbon buildings*. These vary according to the specific context, but in general there are three *key strategies for achieving zero carbon buildings: Improve efficiency, electrify everything, phase out fossil fuels.*[49] For each of these themes and sub themes there are hundreds of available and mature solutions that can be deployed, but as the solution would depend on the specific local context and specific characteristics of the building in question, the pace of retrofitting buildings is in reality very slow. It is time consuming to identify the specific route we would need for a specific location, it is not easy to understand the risks that the building will face in the future, it is not clear what

[49] Climate Action Tracker, 2022

could be the economic gains or losses if the building becomes zero carbon or not, etc. There are many unknowns that in the present means that if we need to retrofit 220 million buildings in Europe by 2050, we then need to do 220 million different retrofit projects. This would be extremely time consuming and most definitely not an efficient way to approach this immense challenge. As we have seen earlier, considering that private investment will have to finance at the very least 56,8% of the decarbonization, the current building by building approach doesn't make any sense because of the time and constrained budgets we have, plus the impact we need achieve: *improve building stock energy intensity by 6% per year between 2020-2030, by 4% per year 2030-2040, and by 3% per year 2040-2050.*[50] How can be possible to know which are the buildings that we are going to intervene each decade in order to keep on track with the commitments ? The first step is mapping, the second prioritizing and the third implementing and monitoring.[51]

Following the *GlobalABC* recommendations, for mapping there are three possibilities: *1) TOP-DOWN - Data Needs: Building stock data (Gross Floor Area), building energy demand, occupancy, energy end-use data (fuel type and consumption), Emissions factors for fuels and electricity used, renovation rates, and new construction rates. - 2) BOTTOM-UP - Data Needs: Measured energy use data from a sample of buildings of the same type, floor area, occupancy, fuels used and end-uses, fuel and electricity emissions factors. - 3) HYBRID APPROACH - requires information on total floor area and, most importantly, specific energy consumption in kWh/m2, which allows for calculating total energy use for different end-uses, building types, climate zones, etc. at the level of a region, country or city. The Hybrid approach can be use on a smaller scale, when it is important to analyse different influences on energy use and GHG emissions (e.g. in different building types or climate zones), or in cases where there is a lack of data and need for detailed assessment on larger scales (country, region, etc.).*[52]

For prioritizing, a normal capitalistic approach would define that we should intervene the buildings that with the less amount of investment will generate the maximum amount of impact. In a context where we are conscious of the climate projections we also need to consider the impact of the intervention as in the year 2050. As a real world example, the *AFD*[53] which is a development bank in the business of financing the green transition in different subjects, would prioritize by first of assessing the amount of investment and the impact in GHG reduction and secondly, by comparing the scenario of not doing nothing v/s implementing the project, both in the year 2050 with the specific location-based climate projections.

When the *EU Renovation Wave Strategy* says that we need to retrofit 220 million buildings by 2050, we actually don't immediately know how many homes or people we are talking about. Usually, according to the mapping recommendations by the GlobalABC we mentioned a couple of paragraphs ago, we will need to know at the very least the square meters of the floor area and the amount of energy consumed. The wave should go through from the most

[50] UNEP GlobalABC, 2021b
[51] UNEP GlobalABC, 2019
[52] UNEP GlobalABC, 2019
[53] AFD Group, 2018

vulnerable homes, the ones that are losing its value faster, until the 100% of the country residential stock is net-zero. The first step is to know the vulnerability throughout the country. But how can we encourage privates to invest on mitigations and adaptations action plans ?

<u>2.6) Contemporary strategies addressing the problem</u>

a) 2010

ENEA, Ricerca di Sistema Elettrico: Edifici tipo, indici di benchmark di consumo per tipologie di edificio, ad uso scolastico (medie superiori e istituti tecnici) applicabilità di tecnologie innovative nei diversi climi italiani; A.P. Corgnati, E. Fabrizio, L. Rollino; Report RSE/2010/190; 2010.

Introduces an analysis made on Italian buildings in order to establish their energy needs. They calculate using the day-degree days, volume, area and other physical characteristics of the buildings, with energy consumption statistics all within different categories. They manage to create statistics on buildings energy consumption by type and explains how legislation in Italy requires to provide the climatic zone in order to determine the median seasonal performance of the building. They analyse the energy consumption by hour on space illumination, heating and cooling in W/sqm, through the different seasons, therefore profiling the energy needs for each category during the different months of a year. They provide a study about the efficiency of solar panels in terms of amount energy that could be produced, for the cities of Milano, Roma, and Palermo on each month of a year. They calculate the percentage of the energy needed and how much solar panels can provide. Milano 75%, Roma 56%, Palermo 62%.

b) 2017:

GBPN Global Building Performance Network, Common Carbon Metric 2.0: CCM2.0, Joint UN Environment - UNFCCC Workshop in mitigation in the building sector; Bonn, Germany August 1 2017

Introduces a comparison between Top-Down and Bottom-Up energy and emissions calculation, recommending the Top-Down method for administrative subdivisions statistics, as Bottom-Up is better on specific mitigation projects. The hybrid approach uses the square meters of the building and also obtains kWh statistics. It suggest to establish a future line scenario as for the trends in energy demand and emissions.

c) 2018:

ARUP, Ellen Macarthur Foundation; From principles to practices: First steps towards a circular built environment, 2018

It provides a strategy on how to achieve a circular built environment in projects through a specific methodology. It proposes that projects main stakeholders are policymakers, investors and construction clients, therefore alliances should emerge when following the same goals.

d) 2019:

Uk Government Department for Business, Energy and Industrial Strategy; Accelerating The Low Carbon Transition: the case for stronger, more targeted and coordinated international action.

Identifies the 10 main sectors that require to be coordinated and work under the same principles and goals: 1) Power; 2) Agriculture & land use; 3) Light road transport; 4) Heavy road transport; 5) Shipping; 6) Aviation, 7) Buildings, 8) Steel, 9) Cement; 10) Plastics; while also providing a general and sectorized strategies.

e) 2020:

Morgan Stanley Institute for Sustainable Investment; Climate transition in a portfolio context: what matters and what to measure; July 2020

At global scale projected emissions in 2030 with current policy scenario will be around 59GtCo2e, while in order to reach 1.5° degree limit, it should be 24GtCO2e by 2030 and 0 by 2050. They explain how there are three types of companies when transitioning to a lower carbon economy: 1) greater climate transition risk; 2) minimal or no (net) impact on transition; 3) they benefit from the transition to lower-carbon economy. They say that their index is not taking in consideration possible tax penalties or incentives that local government has in place, but it is clear that the decarbonisation targets involve the 100% by 2050.

New Economics Foundation; Homes fit for the future: the retrofit challenge, how will we finance the decarbonisation of homes in Wales to support our net zero ambitions ? Executive Summary

In Wales they estimate that 64% of total investment will need to come from private finance, energy companies or self-funding by property owners. They provide a methodology that address the climate targets, reduces fuel poverty, improve health outcomes and creates jobs.

European Commission; A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives

They target 35 million buildings across Europe that by 2030 should be retrofitted in depth (+60% energy savings), providing a pathway to achieve it. Energy performance certificates (EPC) should play an important role while setting by year targets of performance and making the European Building Stock Observatory as the official repository of data about the building stock and its energy performance, driving efficiency to analyse the data. They also provide sectored strategies ready to implement and what was being worked on and recommend a ‘participatory and neighbourhood based approach’ for local strategies that maximise co-benefits as positive energy districts can be achieved faster through their three areas for buildings retrofit: ‘tackling energy poverty and worst-performing buildings’, ‘renovating public buildings such as administrative, educational and healthcare facilities’, and ‘decarbonising heating and cooling’; and working together at all levels with the same goals while creating jobs, improving quality of life and reducing emissions.

Green Energy Community, Climate-KIC, Agenzia per l'energia e lo sviluppo sostenibile, ENEA, Università di Bologna; Le comunità energetiche in Italia. Una guida per orientare i cittadini nel nuovo mercato dell'energia,

> They say that by 2050, in the EU, 264 Million residents will be prosumers in terms of energy, and that would account for 45% of the grid renewable energy. Energy communities are more efficient and create other benefits when they unite with the objective of produce, consume and administer the energy from their local energy infrastructure that is injected into the national grid. Introduces the concept of collective autoconsuemption of energy produced by renewables through the electric grid, and how the sharing economy involves three stakeholders, producers, users and intermediaries, to work towards the same goals creating communities founded on collaborative platforms that has positive economic, social and environmental impacts.

Laura Gabrielli, IUAV University of Venice, London Industry Seminar CRREM-ERES; 1st Panel: Climate change impact on real estate, uncertainty and solutions. Stranding Risk. Climate change, stranded assets, stranding risk. September 2020

> She explains the causes for stranding, the stranding risk, value and projections, presenting the case for historic buildings in Italy for energy restoration. Usually historic buildings have very low energy efficiency. Italy contains 60% of the world's cultural heritage and therefore there is a trade off between monument conservation and energy efficiency. She points out that the laws '192/2005 and 311/2006 relieve historical heritage from energy efficiency obligations "in cases where compliance with the requirements would imply an unacceptable alteration of their historical and/or aesthetic characteristics"'. This applies to 8% of the Italian building stock. In a few years, these buildings will probably become stranded if no energy restoration plan is in place.

f) 2022:

Climate Action Tracker, Decarbonising buildings. Achieving zero carbon heating and cooling, March 2022.

> Through 13 case studies from Sweden, UK, China, US, Germany, Netherlands, Australia, EU Private Finance for Energy Efficiency Instrument and Spain, they identify solutions and propose a clear strategy at all levels of technologies, minimum energy performance standards, Financing, Stakeholders and finally what is needed to transform the building sector.

CRREM & UNEP Finance Initiative; Managing Transition Risk in real estate: Aligning to the Paris Climate Accord, March 2022.

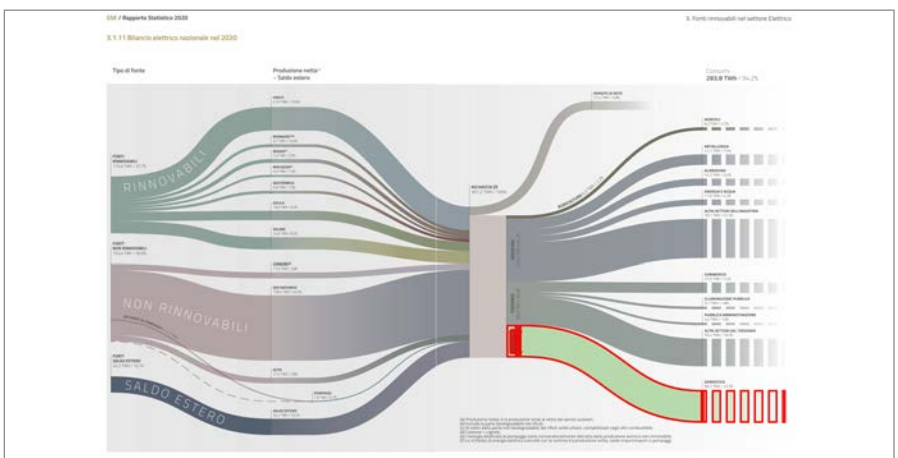
> Analyses the results 'of a group of real estate investors and banks who piloted the use of CRREM as part of UNEP FI's TCFD programme'; and unites it with other relevant climate challenges in order to present recommendations for the real estate sector. Solutions to Climate Risks also involve Transition Risks like 'rising costs due to pricing-in of carbon emissions (through carbon taxes and pricing schemes), market effects, technological disruptions, legal liabilities,

energy efficiency and other regulations and reputational risks all of which can impact property values'. Properties that fail to meet market expectations and regulatory requirements are stranded assets. 'On-site renewable energy production offers untapped potential for further improvement of the GHG profile'. Through the CRREM tool, which provides factors of the transition risk for each country and sector pathways for decarbonisation 'aligned and accepted by the leading international organisations and initiatives', it is possible to design a timetable for retrofit actions that avoid becoming stranded while aligning with the Paris Agreement. It also produces the risk-management indicators typically used in 'credit risk decisions and loan books analysis', therefore increasing transparency and awareness of the risks.

Gestore Servizi Energetici, Gruppi di autoconsumatori di energia rinnovabile che agiscono collettivamente e comunità di energia rinnovabile. Regole tecniche per l'accesso al servizio di valorizzazione e incentivazione dell'energia elettrica condivisa, April 2022.

It explains the procedure to connect to the national grid network and the benefits currently in place for energy communities under 200kW.

It is clear that in the last few years since the problem became evident, the retrofit problem has been studied and being worked on at different levels in different countries and international organisations. In the case of Italy we see that the regulations are moving forward and by 2030 the plan is to add 63 GW of renewable energy into the grid (solar and wind), as the European Green Deal mandates[54]. The whole Italian residential stock consumes around 65 TWh (23.3% of Italian energy grid)[55].



Source: GSE, 2022a, pp.46-47

Mathematically, the amount of renewables that are required to be installed by 2030, if they are all installed and operational, they can easily provide energy for 100% of the homes (considering nowadays 152 kwh/sqm national residential average), at least statistically. A part

[54] European Commission, 2020
[55] GSE, 2022a, pp. 46-47

of the problem can be solved, but homes still need improve their energy consumption to achieve to achieve by 2050 the net-zero targets. On the same document of the EU Renovation Wave, the cost is estimated at €100.000 per building.

If the profits that the new 63 GW of renewables are used to implement the decarbonization of the grid, the retrofit of buildings can easily be paid on steps as there are still 29 years left. Not only the finance problem would be solved. After the whole local community retrofitted their own homes and buildings, revenue from the same local renewable energy projects could be used on enhancing the local community public spaces. Each energy community or cooperative with a yearly income of €500.000 for 20 years that will be used to pay for the retrofit, and after on improve public spaces.

From regions to provinces to municipalities, becoming net zero is a challenge that requires a unified strategy. In Italy we have around 8000 municipalities in 107 provinces and 20 regions, therefore it is needed first to identify the levels of vulnerability in order to categorise by priority. The proposed method will go from identifying climate change vulnerability at a national scale, to a localized decarbonization strategy.

Section 3: Methodology

The proposed methodology is divided in three phases: i) data collection; iI) data generation and analysis; iii) decarbonization strategy. Each of them have a specific objective: i) to understand the national current situation of the residential stock and the local climate change projections; ii) analyse the stranding risk of the residential stock and how wind turbines or solar photovoltaic panels can reduce it; iii) provide a localised decarbonization strategy for the residential stock to achieve net zero by 2050.

Each of these phases is composed by primary steps that are performed sequentially. Their name are the subject that is addressed on that step. Some of them include sub-steps where their names indicate the specific sub-subject. This because it is important to differentiate the specifics of each of the steps in order for the method to be replicable, therefore a short explanation is provided on each.

<u>3.1) Phase 1: Data collection</u>

It is not possible to propose a solution without understanding the problem, so as a first step it is needed to perform an analysis of the current situation of the country residential stock. Climate projections, amount of population and primary homes, their distribution and value, their energy consumption, wind turbines and solar panels potential, are all independently important indicators that together will allow to perform a climate risk analysis on the second phase, and a vulnerability and acceleration assessment on the third.

3.1.a) Climate projections

For planet Earth, the official climate projections are the ones that are given by the IPCC. They were latest updated on August 2021 through the AR6 WG1 results, which provided not only written reports, but also an Interactive Atlas[56] where it is possible to explore the different scenarios and variables that are in deep explained on their reports. The interactive atlas allows everybody to download a NetCDF file that contains geo-referenced information for the variables selected, and therefore importable on a GIS software. As every place has a different climate projection, and each country, region and municipalities have their own buildings regulations, localized analysis becomes fundamental. In the case of Italy, the law establishes different climate zones based on annual mean temperatures, therefore with the IPCC temperature projections it is possible to establish the projected zones at a specific time for a specific place.

+ IPCC AR6 WG1 EU CORDEX Projections

In the specific case of this analysis step and for the case of Italy, the variables selected from the IPCC interactive Atlas are the following: Dataset: Model projections CORDEX EUROPE; Variable: mean temperature; Quantity & Scenario: Quantity change in ºC; Period Medium term (2041-2060), Scenario rcp8.5, Baseline 1995-2014; Season: Annual. The exported netCDF file provides the localized temperature increase projection.

+ Climate zones 2022

In Italy, the law establishes that each municipality has a “Degree days” (DD) value and therefore a Climate Zone Category. Italian DD are equivalent to ‘Heating degree days’ in other countries such as the US or UK, which also have ‘Cooling degree days’. In Italy in 2022 the climate zone categories are 6 and depend on the HDD Value that the government assigns to each municipality[57]: A (under 600), B (600 to 900), C (900 to1400), D (1400 to 2100), E (2100 to 3000), F (more than 3000). The categorization helps to understand the energy consumption for space heating, as the bigger the degree days value, more energy will be needed to maintain a comfortable temperature.

+ Projected Climate zones for 2050

The ‘IPCC AR6 WG1 Interactive Atlas’ provides the projections for heating and cooling degree days, therefore through GIS, considering the projected HDD it is possible to establish the Italian climate zone that is projected for each municipality in the mid term.

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[56] IPCC AR6 WG1, 2021a

[57] Decreto del Presidente della Repubblica, 2022

3.1.b) National Census

The UN Statistics Division (UNSD) provides guidelines for countries to make censuses, and establishes what data should be collected[58]. This data is then aggregated on census zones and publicly available, since it is fundamental for all areas of decision making, from for public institutions to private individuals. Three variables that are always present on censuses are considered for this analysis, therefore they should be available on all the 200+ countries members of the UN. The granularity of the data depends on each country, and are grouped by census zones. Usually they are smaller than municipalities. In some cities the granularity goes deeper into block by block or even building by building, so in those cases we could plan on a more detailed scale. In the case of Italy, the government's agency in charge of the statistics is called ISTAT, and at the time of this research their latest census available is from 2011 that contains census zones smaller than municipalities. For reference, around 8.000 municipalities and 350.000 census zones are detailed on the Italian ISTAT 2011 Census.

+ Primary homes: ISTAT Census 2011 Variable A2
The total number of primary homes in the census zone.

+ Total residential square meters : ISTAT Census 2011 Variable A44
The total number of square meters of the primary homes of the census zone.

+ Total resident population: ISTAT Census 2011 Variable P1
The total number of people that live on the census zone.

3.1.c) Local Indicators of Spatial Association

Agglomeration is a very relevant variable that it is needed to be completely understood, as it allows identify the density of homes on different places and the national tendencies, regardless administrative borders. Through GIS software it is possible to apply an algorithm known as Local Moran's Index, LISA, which classifies objects according to their similar neighbours, thus allowing to answer questions such as where there are more homes, what are the most usual densities of homes or which are the most agglomerated places; within many possibilities that help us understand the distribution.

+ Country wide LISA on Primary Homes, ISTAT census 2011 variable a2
Through GIS software, a Local Moran's I calculation is made on the census variable containing the total number of primary homes in the census zone, in order to establish the agglomeration index, number of neighbours, and other variables depending on the software used. In the case of this research, these analysis was obtained through the software 'Arcgis Pro 2.9' and its tool 'Cluster and Outlier analysis (Anselin Local Moran's I)'.

[58] UNSD, 2017

3.1.d) Residential square meter value

The stranding risk is an economic risk, and therefore it is needed to know the economic value of the property we are analysing. The granularity of our data will determine the granularity of the results. There is no doubt that all properties have different valuation but still we can aggregate and establish a comparable index, such as the sale value by square meter. This statistic is usually provided by local governments and/or private real estate companies. In the case of Italy, a private company called immobiliare.it is the largest residential properties portal for sale and rent of homes and they provide every month the average price by square meter for each municipality in the country.

+ Average residential €/sqm by province

Because of the method used on the stranding risk analysis that will be explained at its time further on, for the case of this research it is identified the residential average square meter price by province as of June 2022.

3.1.e) Energy procurement

Energy consumption statistics and the energy matrix used by homes, is information that is extremely hard to access, specially when in need to compare the different local administrative zones of a country. In many cases reports released to the public by regional or provincial governments or other governmental institutions, deliver one or two years old statistics (for example in the case of Italy from GSE which is the administrator of electrical services we got in 2021 the 2019 statistics and in 2022 the 2020 statistics) and the granularity of the information will hardly go beyond regions. When it does, is on specific cities and therefore not comparable with the rest of the country. In order to solve this lack of information, the European Union funded through a Horizon 2020 grant, a project called Odyssee-Mure which was in charge of the analysis, comparison and categorization of the energy procurement and consumption for each one of the countries of the EU. The result were reports but also a fully categorised database of energy consumption at national level, for each of the countries. It is now possible to obtain from Odyssee-Mure the year national average of power consumption, sources of energy, green house gases emitted, how energy is used and hundreds of other statistics. Since replicability of the method is one of the objectives of this research, the energy information is obtained from Odyssee-Mure database, and therefore ensuring immediate replicability on any European Union country from the same database and ensuring comparable results if other countries were to be analysed in the same way.

+ Energy Matrix: Grid electricity, natural gas, fuel oil, wood, heat.
    + Usage (KwH)
    + Coverage (%)

Each country has a different energy matrix for each of the typologies of properties. For this analysis it is used the information for residential energy consumption from Odyssee-Mure database, for each of the energy sources in terms of quantity and percentage of the total.

3.2) Phase 2: Data generation

There are two topics that need further comprehension in order to develop a better decarbonization strategy. The first is the stranding risk analysis, studied through the CRREM tool, and the second is the potential of wind turbines and solar photovoltaic panels.

The 'Carbon Risk Real Estate Monitor' (CRREM) is a tool funded originally by a European Union Horizon 2020 grant, therefore originally covering all EU countries. It was expanded to other regions and buildings typologies, not only office buildings now, thanks of the support of different sponsors. One of them was the United Nations Environment Program Financial Institute (UNEP FI), 'to further advance the understanding of transition risks in the real estate sector', as it helps to 'understand the magnitude and nature of their potential risk'[59] . CRREM is quickly becoming the standard tool for climate risk analysis, as it groups all the approved pathways for energy consumption and greenhouse gases reductions signed on the Paris Agreement with localized temperature impact of climate change granulated to national zip codes, and through its calculations delivers comprehensible risk related information not only in economic terms, but also in emissions and power consumption. The methodology proposed on this research uses the CRREM tool in order to quantify climate related risks throughout the country, but since the tool is intended to be used to analyse individual buildings, a custom 'assets definition' method is proposed. For each asset it is required to provide at +30 data elements as a table organisation where each line is an asset and each column a specific data value. Through GIS software, a two step asset definition is proposed, grouping by geo-location all the information required for the stranding risk analysis. In the case of this research, all the data is obtained from four sources: ISTAT census 2011, Poste Italiane CAP (zip codes), Immobiliare.it (property values) and Odyssee-Mure energy database.

3.2.a) Cluster definition

If one census zone is considered as an asset, on the case of this research the starting point would be around 350.000 assets therefore it is required to perform a sampling process. As seen from the literature review, specifically where it is emphasised the need for resilient urban and rural communities[60], it is clear that agglomerated homes represent a challenge of its own, as the bigger the agglomeration, the bigger the vulnerability to climate risks and thus their need for resilience. Therefore a stratified sampling process is proposed, where the samples are not random, they are the

[59] CREEM and UNEP FI, 2022

[60] WBCSD, 2021, pp. 38-43

clustered census zones. In order to identify them, an Anselin Local Moran Index analysis (LISA) is performed.

+ Positive spatial autocorrelation on amount of primary homes
    + LISA on Variable A2 (primary homes)
    + Selection of High-High & Low-Low Clusters while disregarding Outliers

An 'Anselin Local Moran's I' spatial autocorrelation analysis is performed, on the case of this research, on Arcgis Pro 2.9 with the tool 'Optimized Outlier Analysis", setting as the analysis field the ISTAT Census 2011 variable A2 (primary homes) and performance adjustment 'Robust (999 permutations)'. Then only the clusters are selected (high-high and low-low) and so we identify throughout the country the clustered primary homes. They are, in Italy, 8.658.485 representing, 35,86% of the country, in 10.307 clusters.

3.2.b) Cluster categorization

+ Aggregation of clusters by
    - Region
    - Province
    - Climate Zone in 2050

Clusters are then dissolved on the fields region, provinces and climate zone in 2050, using the tool 'Pairwise dissolve', obtaining 224 groups that will be used each one as an asset for the stranding risk analysis.

3.2.c) Stranding Risk Analysis on Groups

+ CRREM Tool setup
+ CRREM Tool results
    - Year of stranding
    - Discounted cost of excess emissions (DCOEE)
    - Cumulated excess emissions until 2050 (CEEU2050)
    - GHG intensity
    - Emissions budget 2018-2050

As of version 1.18 (07.02.2022) the tool doesn't include the "Residential" type of use therefore it is needed to be added manually. The Italian residential multi-family paths are obtained from crrem.org and included directly on the back-end. Settings on the tool for each asset are defined: 'Normalise consumption data to 100% occupancy rate" = yes; 'Normalise heating and cooling consumption to weather in year of consumption" = yes; 'Climate change projection (affects future heating and cooling demand)' = RCP8.5. All other settings on setting page are left as default. We obtain a table with different results for each asset, some comparing 1.5ºC and 2ºC targets, according to the Paris Agreement commitments. Since we are using the national statistic of energy consumption provided by ODYSSEE-MURE, some of these results are not relevant for our purpose, but the 'Discounted cost of excess emissions', which indicates the yearly depreciation of assets, it is very relevant for this research. This because its results depend not only on energy consumption but also on the location of the asset (each zip code has a specific carbon risk factor) and the economic value of the asset (each province has a different value). As we use the same energy equation for all assets (according to ODYSSEE-MURE database in Italy the residential matrix is 18,2% electricity, gas 52,1%, oil 6,4%, heat 2,9%, wood 20,4%), this results, highlight the inherent risk of depreciation calculated by CRREM therefore instead of a detailed 'location plus specific energy use of the building‘ result that we would obtain if we have the exact energy consumption of the asset, we obtain the depreciation climate risk of the location, on this case, a province climate zone in 2050 depreciation risk of assets.

<u>3.2.d) Wind and PV Solar panels potential on Provinces</u>

- Estimated savings and payback times
- Comparison of ROI with 5MW limit of installed power.

On the energy industry, projects are usually categorised as ‘mini’ or ‘small’ (depending on the country) when the installed power is under 5MW. In the case of Italy, this category also exists in the law (D.L. 199/2021 Art.9, transition to new incentives) as it is a directive of the European Parliament law UE 2018/2001 (therefore this applies to all countries in the EU) that promotes renewable energy production. In Italy it translates to incentives for up to 5 MW wind farms and a 1 MW limit for all other renewable energy sources. Since indeed it is not comparable the ROI of 1 MW installed power with 5 MW, for the purpose of this research calculations are made with a 5 MW limit for both, wind and solar, in order to compare possible production but also acknowledging that in reality a 5 MW photovoltaic farm are five 1 MW farms in order to obtain the incentives and benefits of the law. In the case of wind, calculations are based on the results that 1 Vestas V150-4.2MW turbine can obtain in terms of energy production based on the World Bank Global Wind Atlas[61] projections (which summarises all official projections and models). This specific turbine is one of the most efficient in the world at the moment of this research and already deployed through Italy on different locations, as it is the perfect turbine for Italian wind speeds, and also manufactured on the Vestas Italian factory at Taranto, Puglia, making the installation, operation and maintenance prices very favourable. In the case of solar photovoltaic panels, the technology proposed is Agrovoltaics, which consist on deploying photovoltaic solar panels on a productive farm in a way that not only allows agriculture on the ground, it enhances the production. Since agriculture production is out of the scope of this research, only production of solar panels is quantified but it is acknowledged that agriculture production could also represent additional economic returns. To quantify the solar production, GSE statistics[62] are used, which are granulated by province. Results are grouped on three categories for energy source choice: solar, wind, and similar roi with wind and solar, which is where a specific project

[61] Global Wind Atlas 3.0, 2019
[62] GSE, 2022b

could be more favourable to solar if the specific agriculture production produces a positive difference.

3.3) Phase 3: Decarbonization strategy

3.3.a) Statistics by Region + Province + Municipality + Climatic zone in 2050

Results from the first two phases are analysed and summarised in order to represent the basis of the vulnerability and acceleration assessments.

3.3.b) Vulnerability Assessment

- Climate risk throughout the country
- Prioritization of interventions by municipality

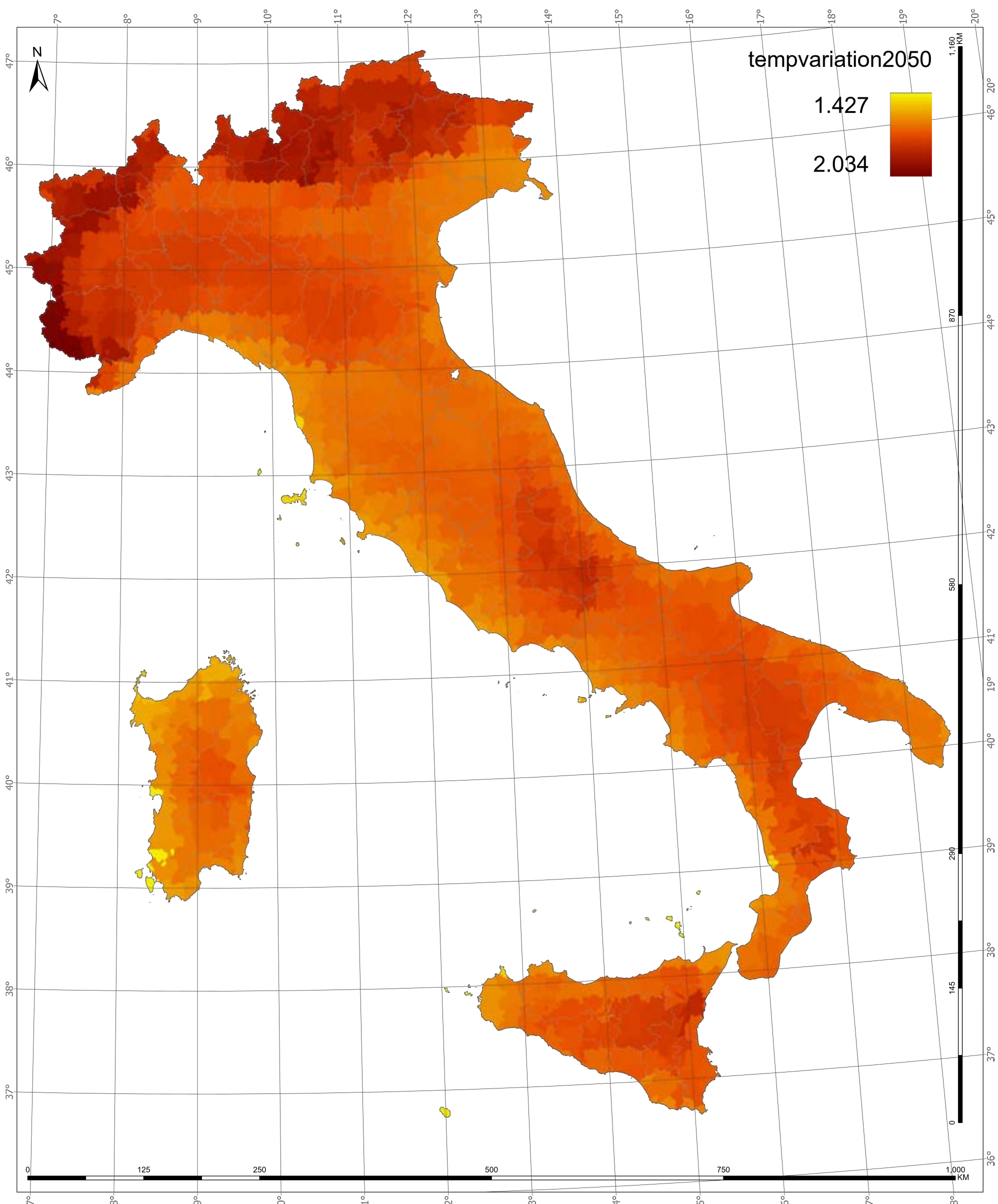
3.3.c) Acceleration Assessment

- Renovation rates
- Renovation depth
- Renovation investment

Section 4: Results

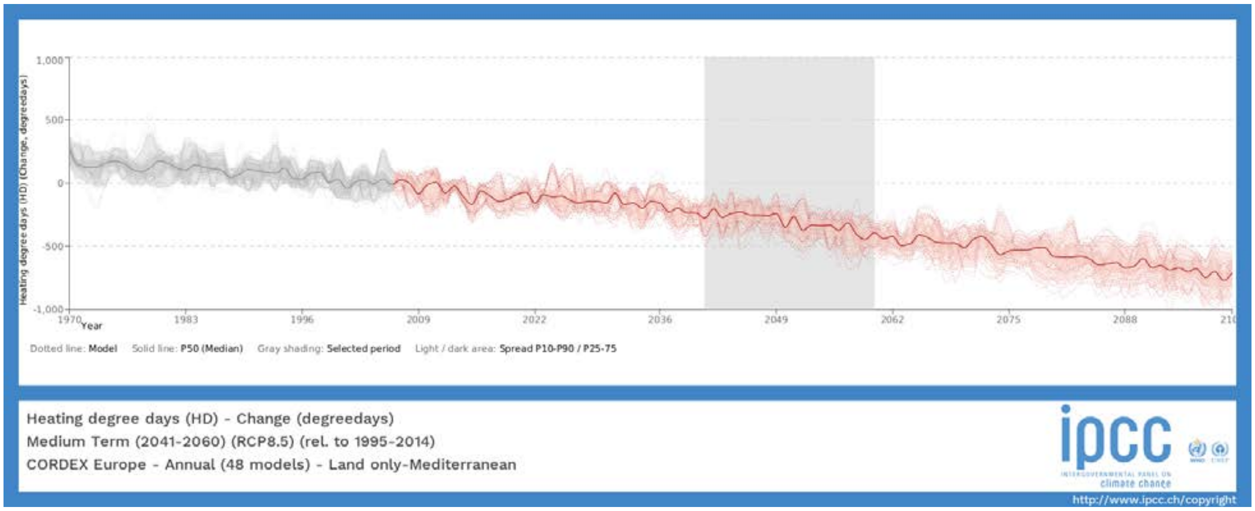
4.1) Mid-term (2050) temperature rise projection

According to the most probable IPCC projections from AR6 WG1[63], by the mid-term, 2041-2060, the yearly mean temperature in Italy will rise between 1,427ºC and 2,034ºC It is worth mentioning that the IPCC AR6 WG2 report mentioned on the literature review establishes on paragraph SPM.D.5.1 that climate resilient deveolpment will be limited after the +1.5ºC overshot and not possible in some regions after +2ºC. .

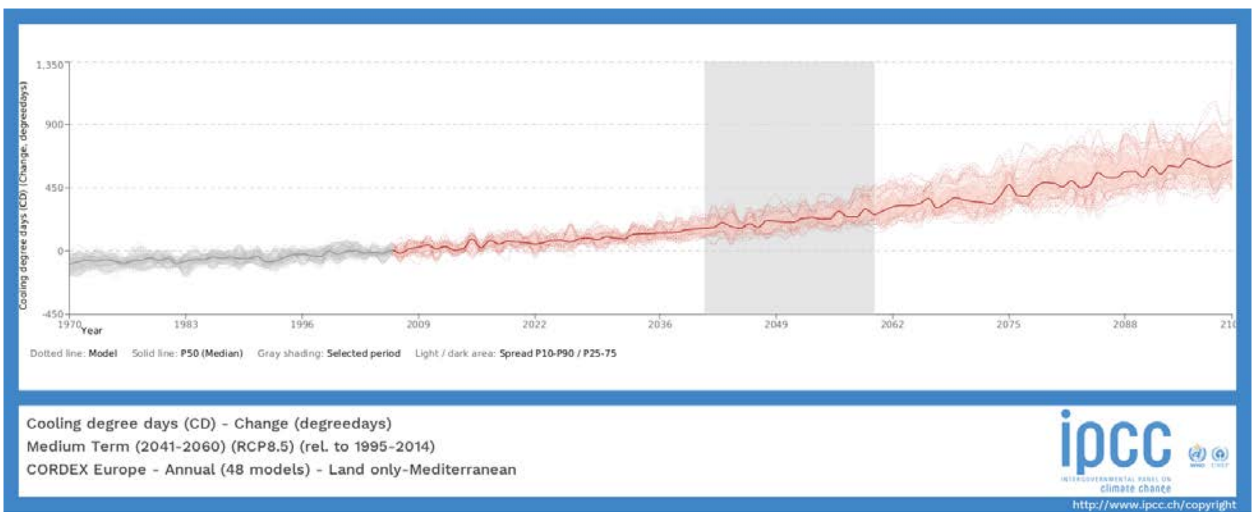


[63] IPCC AR6 WG1, 2021b

As in Italy the government establishes by law that the ‘Heating degree days’ (HDD) variable determine the climatic zone of the municipality, it is relevant to understand the projection of the climatic zones in 2050. Since the temperature is rising, the HDD value will be decreasing.



This means that energy use during the winter for space heating will decrease, as there will be less difference with the outside temperature. Still, it doesn’t mean rising temperatures bring a benefit, because this energy will instead be used during the warmer months to cool the spaces.

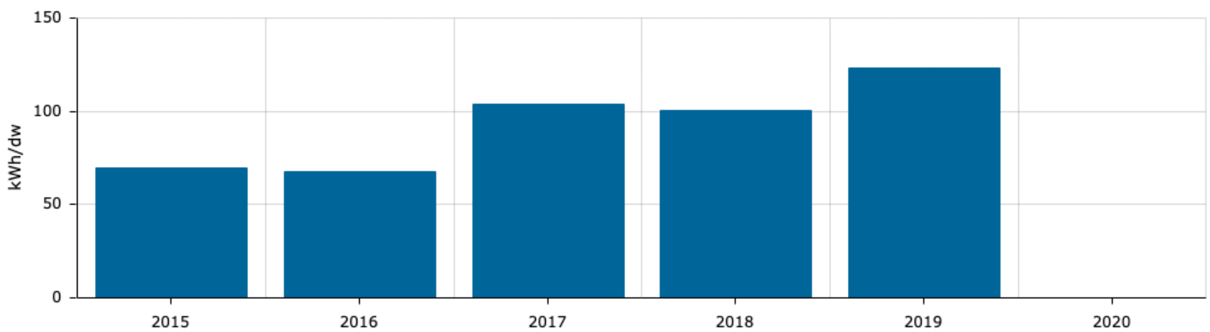


According to the represented model, which as we have seen is the most likely to happen, on the Italian section of the European map[64], by the year 2050 the median decrease for HDD will be 310 points and the median increase of CDD will be 225 points. In terms of energy use for space heating and cooling, translating into Kilowatt hour kWh will depend on the specific building’s degree days determined by its location, the heat loss coefficient of the building and the efficiency of the system used to heat or cool the specific home. For this reason might seem speculative to state an expected value of kWh consumption for space heating or cooling, but ODYSSEE-MURE energy database provides these statistic at a national level and therefore we can gather a general idea of the situation as it has been in the past years.

64 IPCC AR6 WG1, 2021b

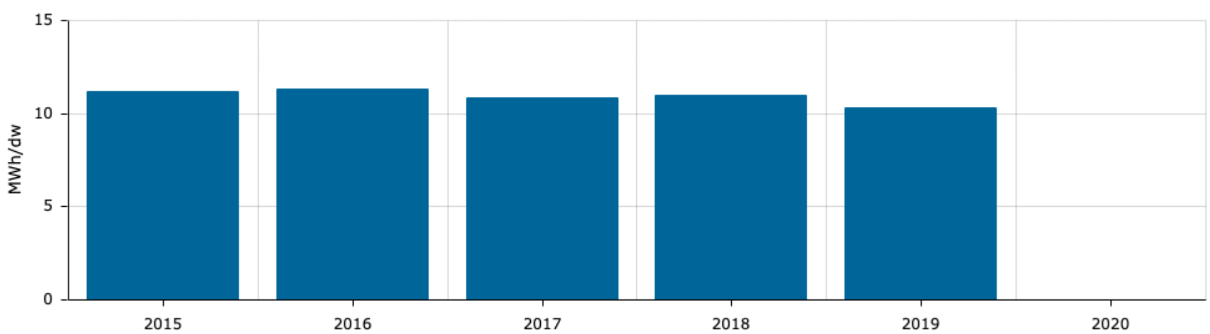
According to ODYSSEE-MURE database, Italian households spent in 2019, the latest year of data for Italy on the database, 123 kWh/dw (per dwelling) on space cooling, and 10332 kWh/dw on space heating. This means that of all the energy consumed during the year for regulating a home interior temperature, roughly, 1,2% was used for cooling and 98,8% for heating.

Italian households: unit consumption per dwelling for cooling



Source: ODYSSEE-MURE

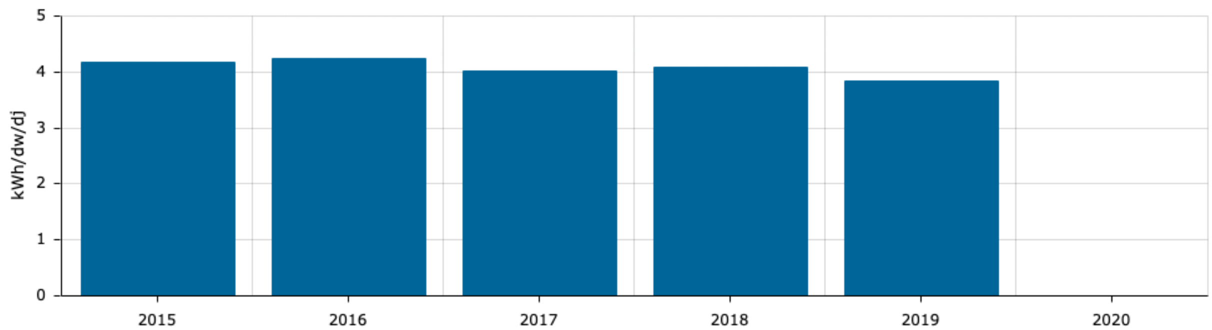
Italian households: unit consumption per dwelling for space heating with climatic corrections



Source: ODYSSEE-MURE

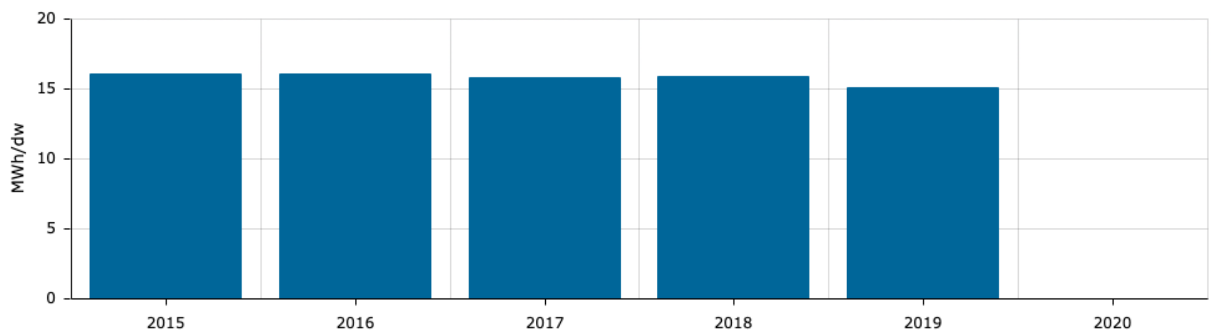
It is therefore understandable that the Italian legislation has disregarded until now the cooling degree days and only considers the heating degree days for determining the climate zones of a home: roughly 99% of the energy consumed for interior temperature adjustment is consumed on heating. In the future, space cooling will probably start to become a bigger consumer of energy, as it is on countries nearer to the equator (Italy spans approximately within latitudes 37° and 47° north) but as said earlier, the heat loss coefficient of the specific building will be one of the key elements to focus on improve. In this context we can consider another ODYSSEE-MURE statistic: how many kWh each home consumes on space heating for each degree day. In 2019 it was 3,83 kWh/dw/dd. This means that if by 2050 we are expecting a mean decrease of 310 HDD, we can also expect a 1187,3 kWh/dw yearly reduction on energy consumption for space heating. Considering that In 2019 the yearly total energy consumption per home was 15078 kWh/dw, this reduction would be roughly just 7,9% if the consumption stays equal by mid century. It probably won't, as the Paris Agreement and the EU green new deal are aiming for a 50% reduction in consumption 20 years earlier, by 2030, and so it is very clear that even without considering the 200% estimated increase in consumption for cooling because of the temperature rise, there is still a huge amount of work to be done in terms of efficiency not only on the building envelope but also on the appliances.

Italian households: unit consumption in useful energy for space heating per degree day



Source: ODYSSEE-MURE

Italian households: unit consumption per dwelling with climatic corrections



Source: ODYSSEE-MURE

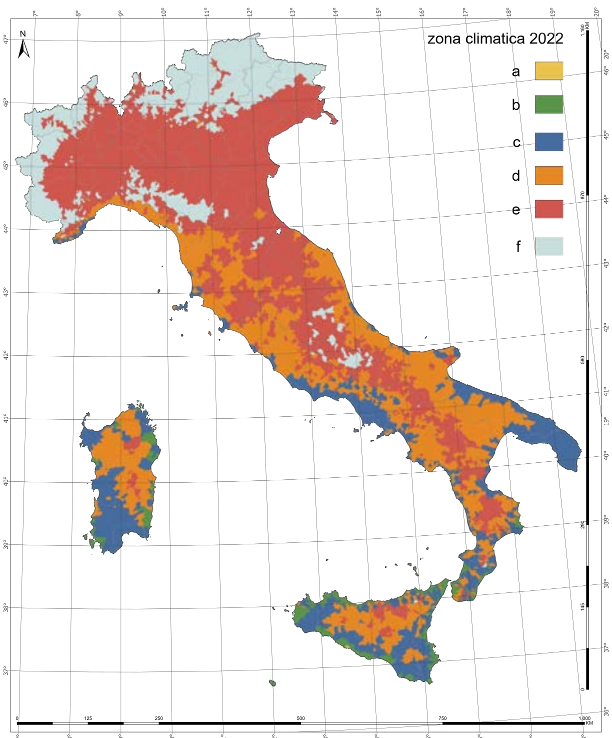
In terms of the climate projections, there are two variables that appear as the most relevant for the purpose of this research:

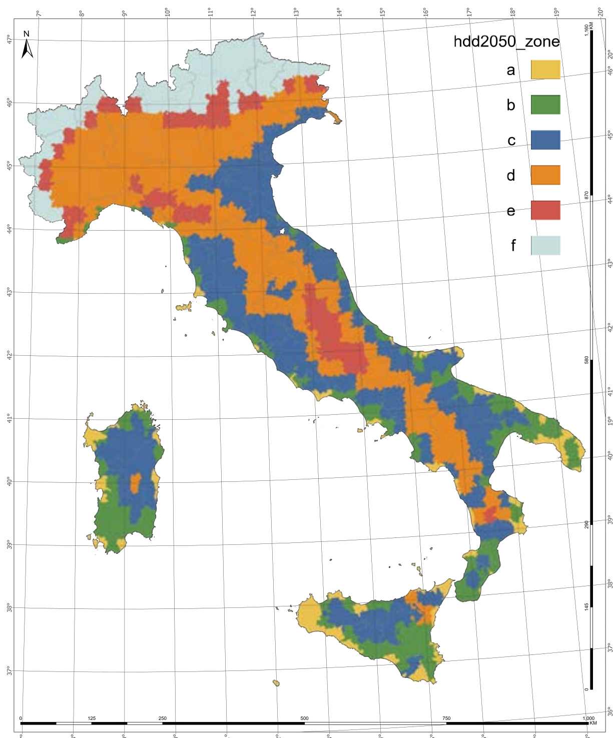
a) according to the projected HDD and current categorization established on the law, on which climate zone a specific municipality will be in 2050;
b) which are the municipalities that can expect the biggest change, and therefore the ones that will have to undergo through more intensive adaptation + mitigation plans.

Through GIS software and the data provided as NetCDF from the IPCC interactive atlas, we can answer these questions. We will then be able to begin to understand the distribution of the residential stock throughout the projected zones, provinces and regions of the country.

	A	B	C	D	E	F
Primary Homes (dw)	9,34%	16,51%	27,32%	40,15%	4,00%	2,69%
Dw m2	9,00%	15,72%	27,43%	41,78%	3,80%	2,27%
Median m2/dw	95,15	97,44	105,00	108,50	97,22	89,37
Residents	9,79%	17,10%	27,26%	39,90%	3,62%	2,33%
Median m2/pp	38,594	38,229	41,826	43,928	44,104	39,435

A good way to clearly understand the climate projections of temperature is to compare the current heating degree days HDD with what it is projected. On the left map we see the categorization for each of the municipalities according to the April 2022 update of ‘Allegato A’ of the ‘412/1993’ Italian law that establishes the degree days and categories, while on the map on the right we can see the IPCC projected HDD values, categorised using the same breakpoints of the current Italian law in order to easily visualise the impact of global warming.



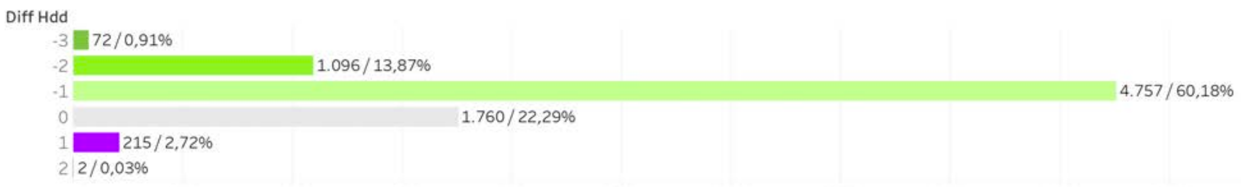


We can clearly see how the temperature is projected to rise on the different parts of the country, making evident that the Alps, in the north, and the Appenine mountains, that span along the country, will maintain lower temperatures, even while warming up. As already mentioned, higher categorization will mean a bigger need of interior temperature adjustment therefore a bigger need for better insulation to reduce the heat loss of buildings and better efficiency of appliances in order to maintain the required energy consumption threshold established on the energy consumption pathway to net-zero defined on the Paris Agreement. In this context, next is to understand the distribution of homes along projected climate zones, but first we can grab an idea in what way municipalities are changing their climate zone

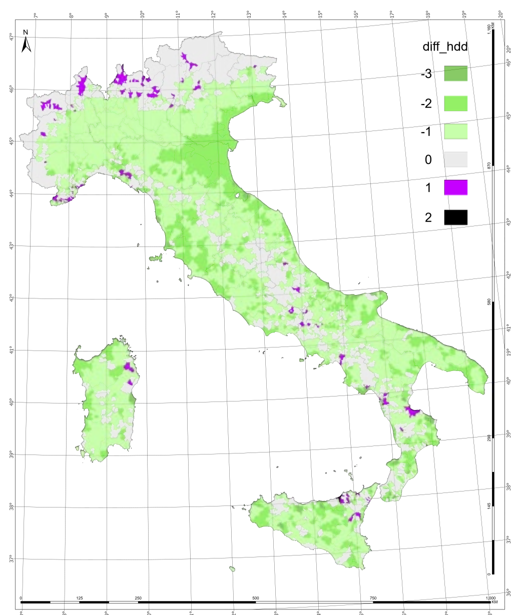
Climate zone 2022 vs Climate zone 2050: how many municipalities per category

On the graph we can see the changes that are projected. The columns group the municipalities that contain a certain climate zone category in 2022, while the rows the ones on the zone category in 2050. The colors are according the 2050 climate zone, for easier reading. This graph shows that most municipalities will decrease their degree days categorization, but some will increase it. For example on the case of the 2022 climate zone categorization E, we see that within all municipalities that in 2022 belong to this category, by 2050 24 will be B, 529 C, 2989 D, therefore decreasing their categorization; 494 will maintain their category E; and 135 will increase their categorization to F. For this reason and for the purpose of this research, specially to assess vulnerability, it is relevant to identify the municipalities that will undergo the most drastic change, specially upwards, as it means their homes will be exposed sooner to bigger need of insulation and efficiency than nowadays in order to consume the less possible energy.

Change in climate zone category 2022 vs 2050: how many municipalities will go how many categories up or down



On the graph we see the amount of municipalities that will go up or down and how many categories, comparing 2022 and 2050 projection. 74,96% of the Italian municipalities will decrease their heating degree days categorization, 22,29% will remain on the same category and 2,75% will increase their categorization. On the map we can visualise the location for each categorization. This classification will be useful to fine tune the vulnerability assessment for phase 3.

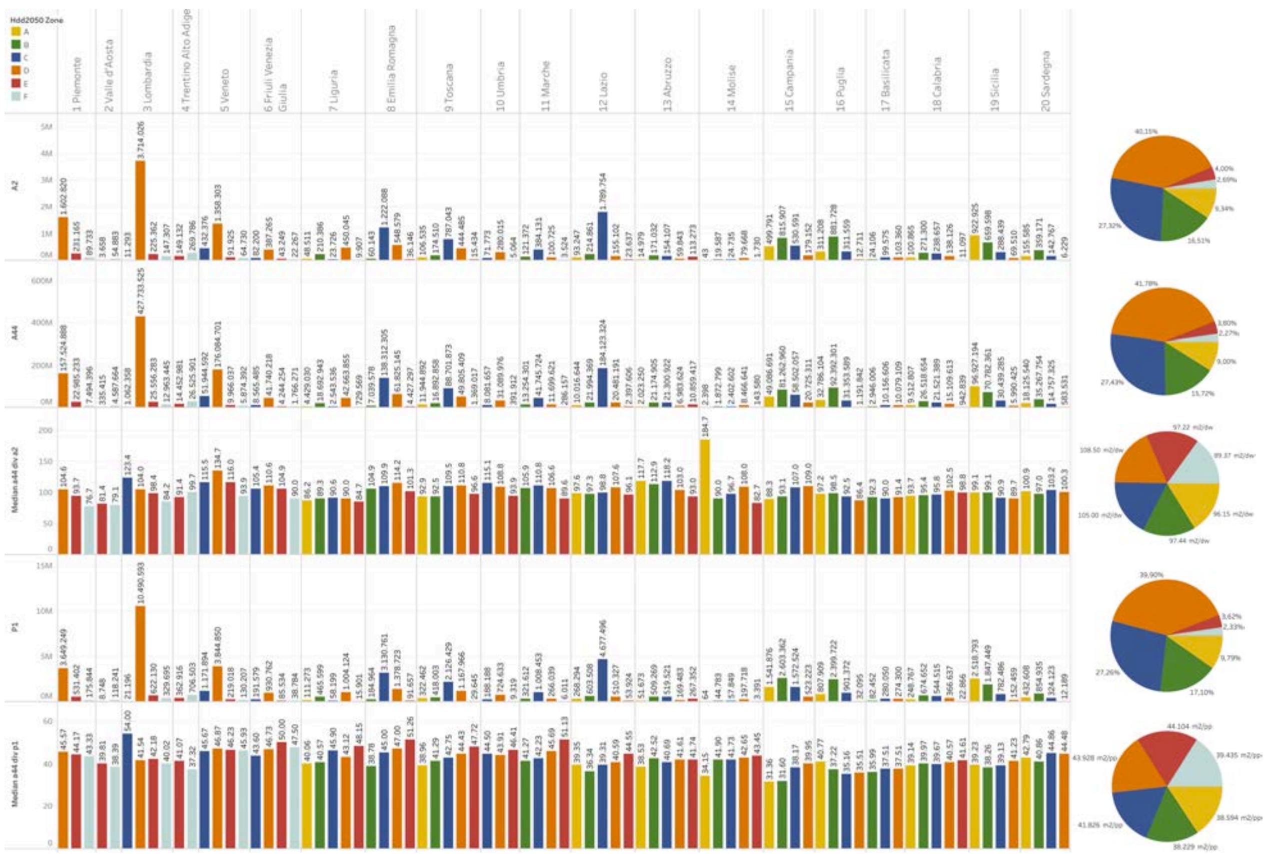


As we have seen on the literature review section, specifically on the 'UNEP GlobalABC, Adaptation of the building sector to climate change' 'Principle 5: data' where it states that projections are uncertain and that action plans should be adaptive because reality might surpass all estimates; and also on `WBCSD, Vision 2050: Time to transform' 'Mindset Shift 2: Resilience' where it states that we should have 'the capacity to anticipate, embrace and adapt to changes in order to safeguard success'; it becomes very clear that any action plan must consider the projected temperature increase, at the very least. Therefore, the current climate zones as of 2022 will not be considered further on, in favour of the IPCC projected climate zones - as we have seen the IPCC projects the heating degree days and the categorization of climate zones is established considering the breakdowns of the current legislation - and so it is possible to include the climate projection on the relevant analyses: in terms of vulnerability, the 2050 climate zone is one of the factors influencing the risks, while in terms of acceleration, not only the 2050 climate zone but also if the categorization is going up or down and how much are factors that we should consider for the final assessments.

4.2) Primary Homes & Population

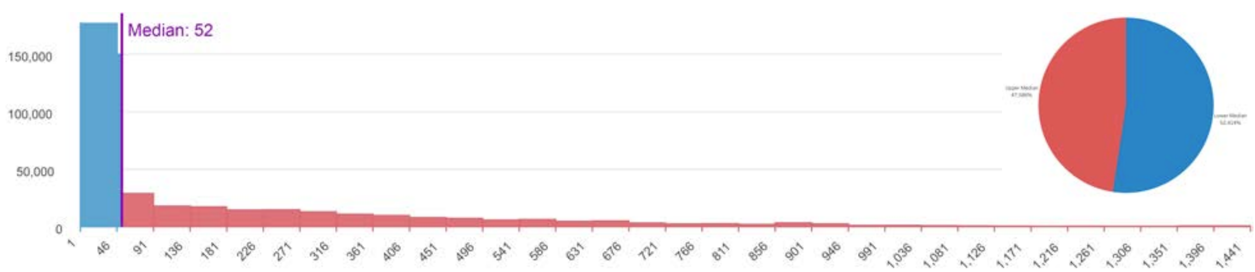
It is very relevant to have a clear understanding about how many persons live on how many homes, not only on the different administrative subdivisions (regions, provinces, municipalities) but also on each of the projected climate zone.

ISTAT Census 2011 variables A2 (primary homes), A44 (a2 sqm), Median a44/a2, P1 (residents), Median a44/p1, by 2050 climate zone

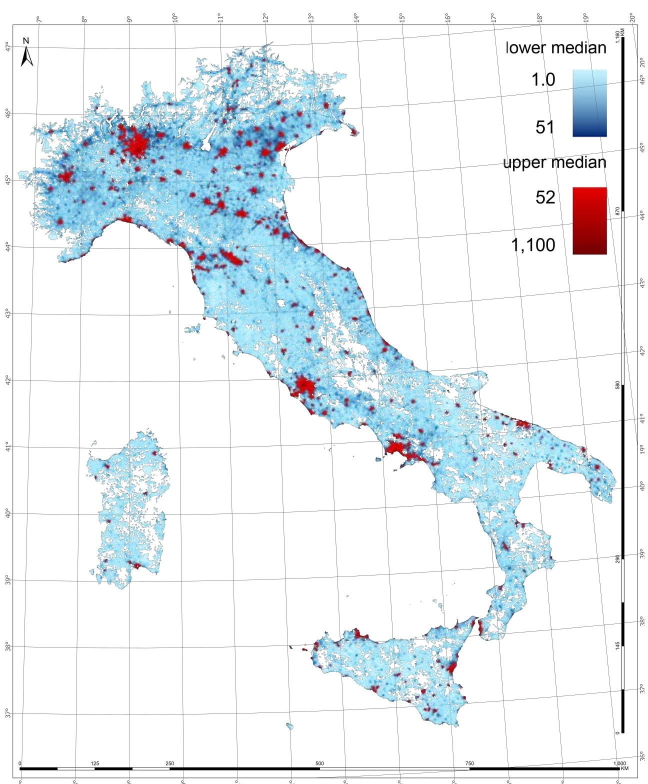


Considering the climate zones projected for 2050, it can be seen from the graphs and table that most homes and population are located, in descending order, on zones D, C, B, A, E, F. Considering that higher categorization means it would require bigger interior temperature regulation for space heating, it is a good finding that 2050 climate zones E and F account for less than 7% of primary homes and less than 6% of residents of the country, but concerning that zone D accounts for roughly 40%. Indeed the higher the 2050 climate zone categorization, higher will be the climate risk, but considering the 2050 climate zone with the population and homes on it, then the risk by 2050 climate zone in descending order would be D, C, B, A, E and F. Yet there are other factors in play in order to produce a better vulnerability assessment.

A key element is to understand how the homes are distributed on the territory in terms of density. Understanding agglomeration is fundamental. For this it is performed a LISA (Local index of spatial agglomeration) analysis through GIS, which produces several data results. In order to understand them better, from the generated data the median point is taken, and then each object is categorised as upper or lower median, which means that the object's LISA is higher or lower than the median of the country. This allows to understand the distribution of homes and clearly identify the main cities and towns.



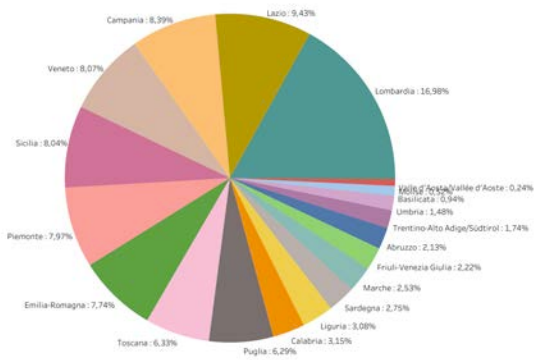
Density of primary homes is represented by classifying the amount of neighbours each of the census zones have. All census zones with no primary homes are excluded and so mathematically we can see that the median amount of neighbours a census home have is 52. In blue are represented all census zones that have between 1 and 51 neighbours and in red the ones that have 52 or more. On the graph we see the distribution by value and on the map the distribution by each color gradient, effectively identifying the location of agglomerations of primary homes, such as cities and towns. It is also possible to state that 47,586% of homes have more than the median agglomeration (red) and use 3,25% of the Italian soil, while the other 52,414% are more dispersed and use 71,9% of the



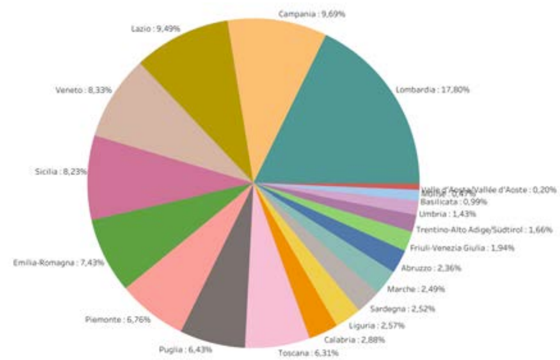
Italian soil. On 24,85% of the Italian territory there are no primary homes at all. Regarding the regional distribution, the same information can also be classified and so it can be understood which regions account for more residents and primary homes and which less, and how is the distribution throughout the country.

ISTAT Census 2011, Total distribution

% of primary homes by region

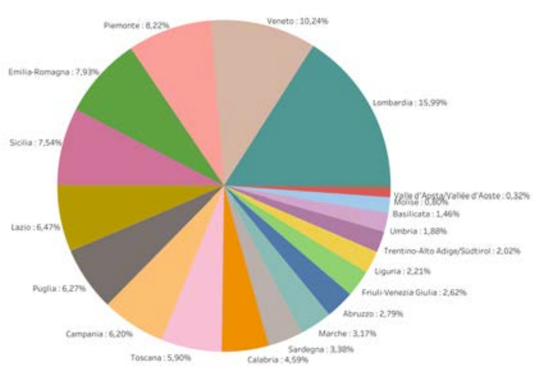


% of population by region

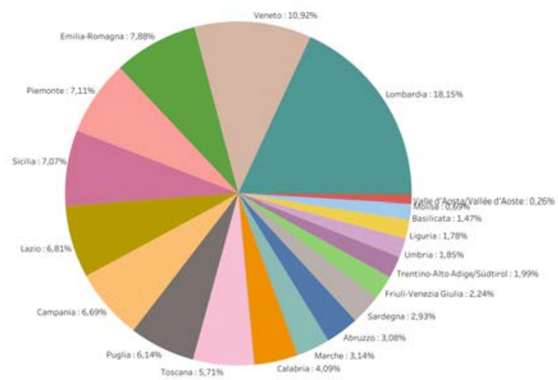


ISTAT Census 2011, Lower median

% of primary homes by region

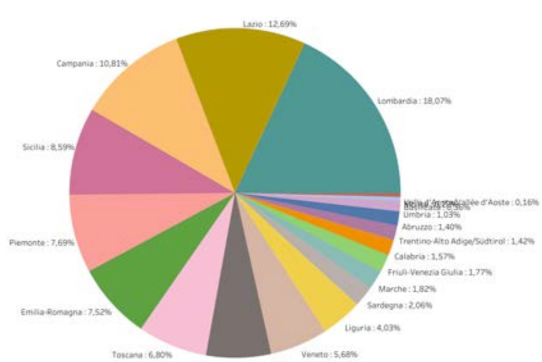


% of population by region

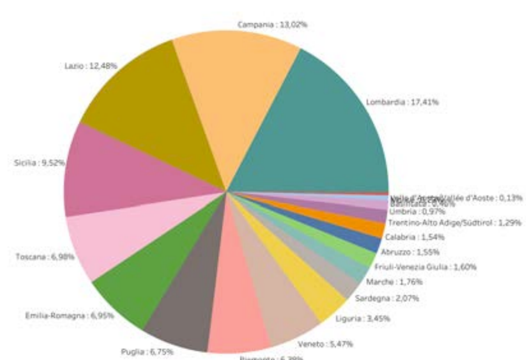


ISTAT Census 2011, Upper median

% of primary homes by region

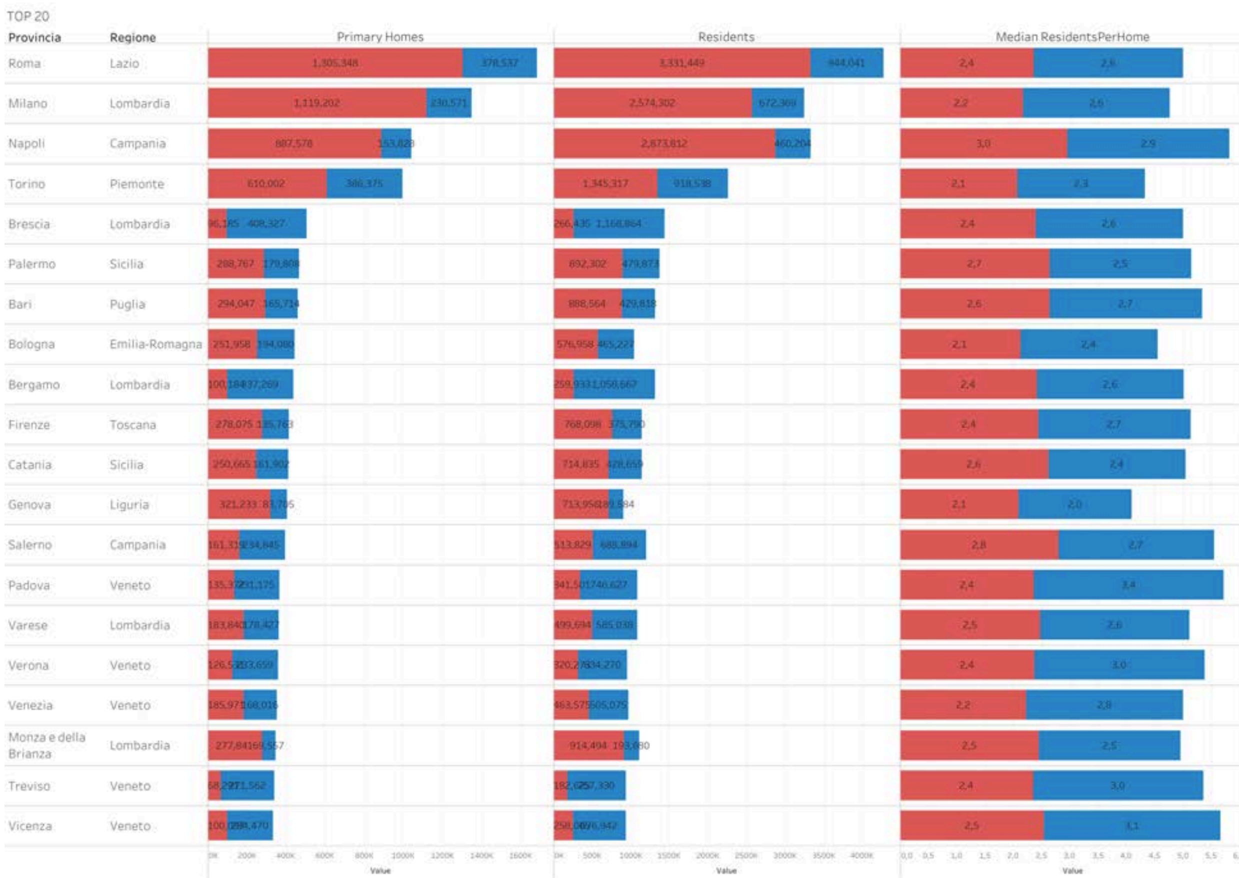


% of population by region



It becomes clear that by all means the Lombardia region accounts for the majority of homes and population, and Valle d'Aosta the minority. In between we can see mixed results depending on the variable we focus.

A further analysis is understanding the same distribution but instead of by region, by provinces. Specifically interesting is getting to know which are the top 20 from top to bottom



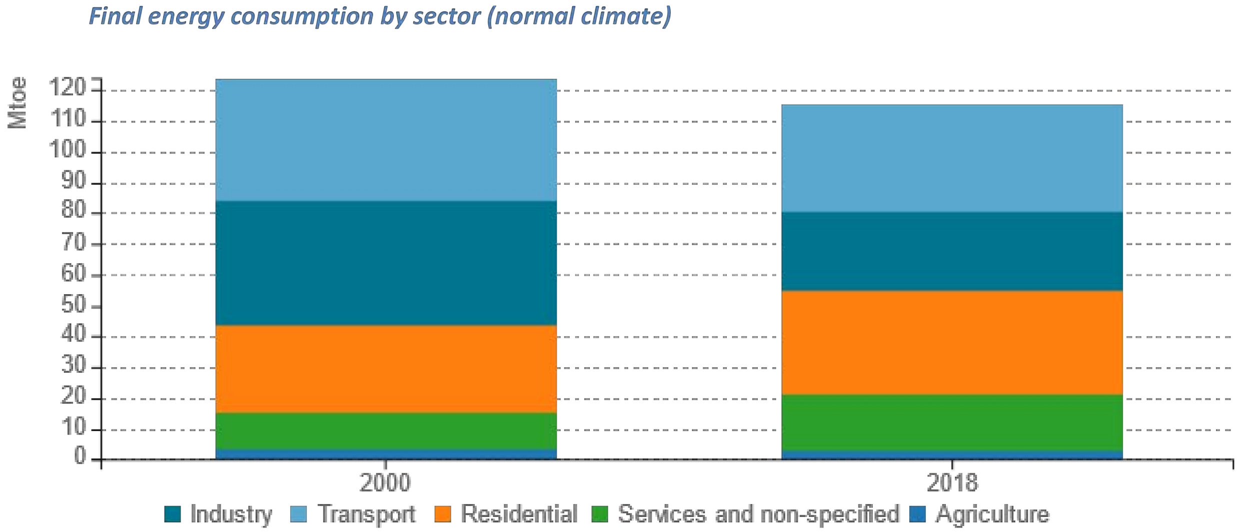
It can be seen that 21,01% of all the primary homes are condensed in the top 4 provinces: Roma 6,98%, Milano 5,59%, Napoli 4,31%, Torino 4.13%. On them 20,76% of the total Italian population lives, and they use 3,77% of the Italian soil.

These statistics give use clear understanding of the distribution of homes and population. The agglomeration of homes is a key variable for this research vulnerability identification and acceleration goals, as the retrofit challenge involves achieving certain thresholds by certain years, and therefore by knowing the localized density a better action plan can be deployed.

<u>4.3) Residential Energy Consumption</u>

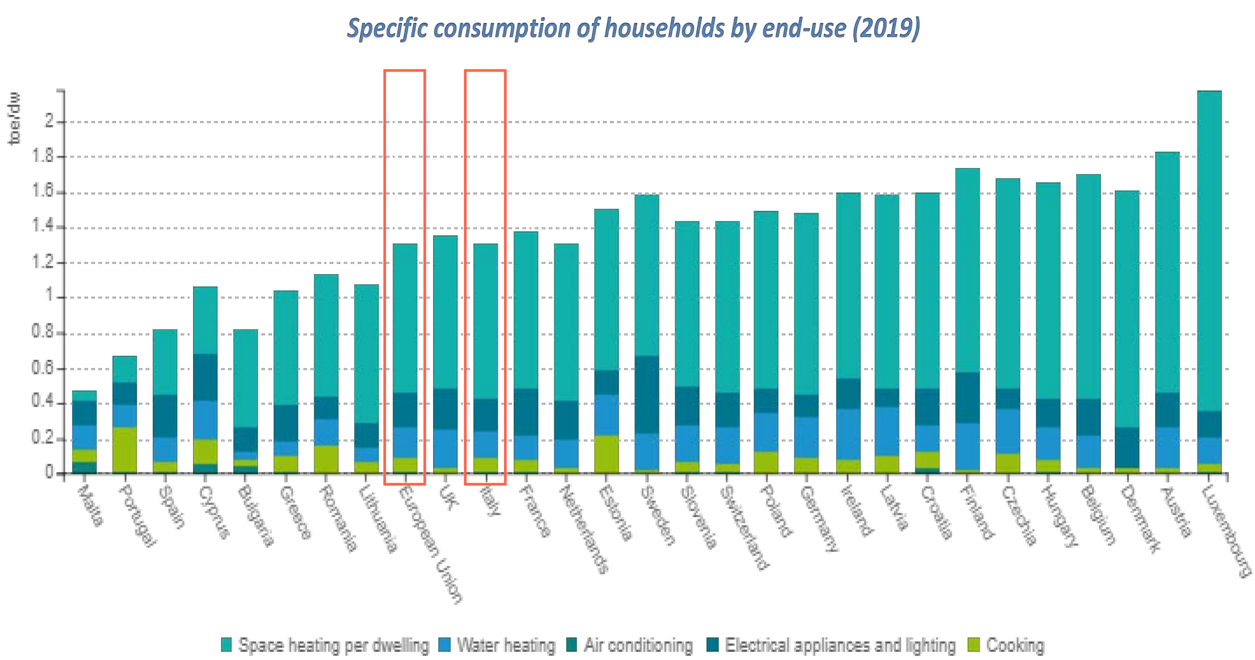
Another key element is how much energy is consumed by homes and how. Thanks to the EU Horizon 2020 project ODYSSEE-MURE, we can know and even compare all EU countries.

In Italy the residential sector uses around 23% of total energy.



Source: ODYSSEE-MURE, Italy energy profile, March 2021

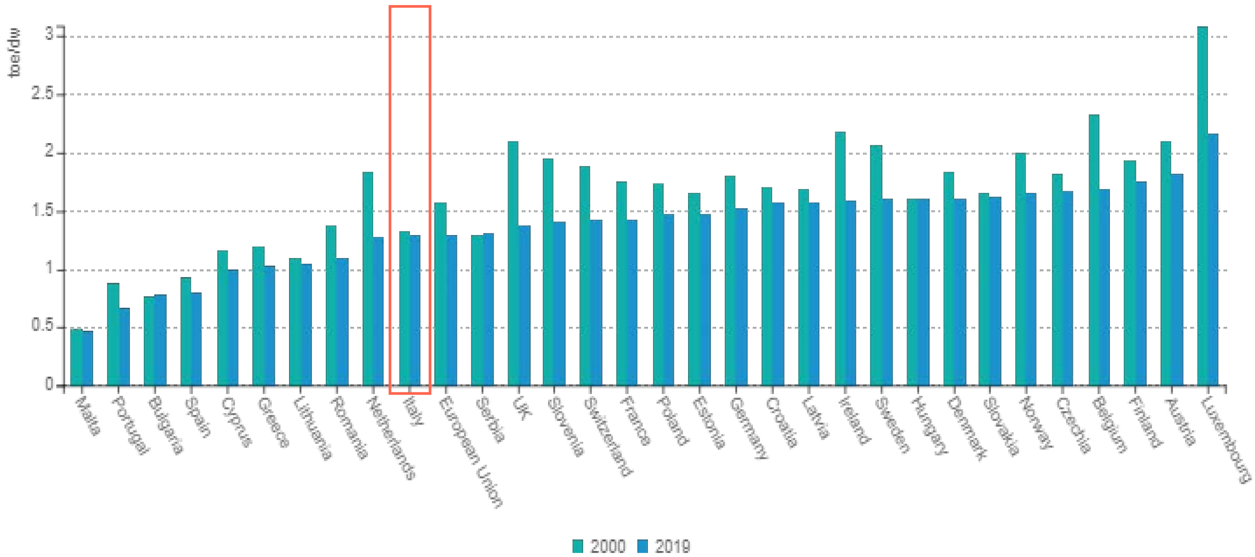
Compared to rest of EU countries and the EU average, it is very similar:



Source: ODYSSEE-MURE, Sectorial energy profile - Households

Italian homes energy consumption is relatively stable comparing 2000 and 2019:

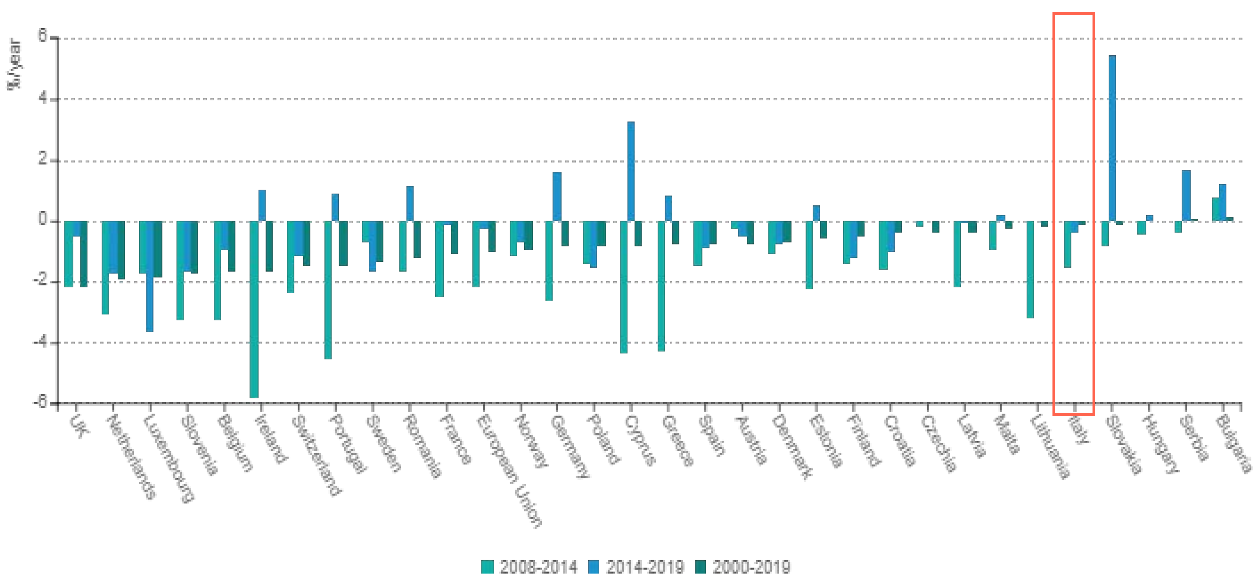
Average consumption per dwelling (at normal climate)



Source: ODYSSEE-MURE, Sectorial energy profile - Households

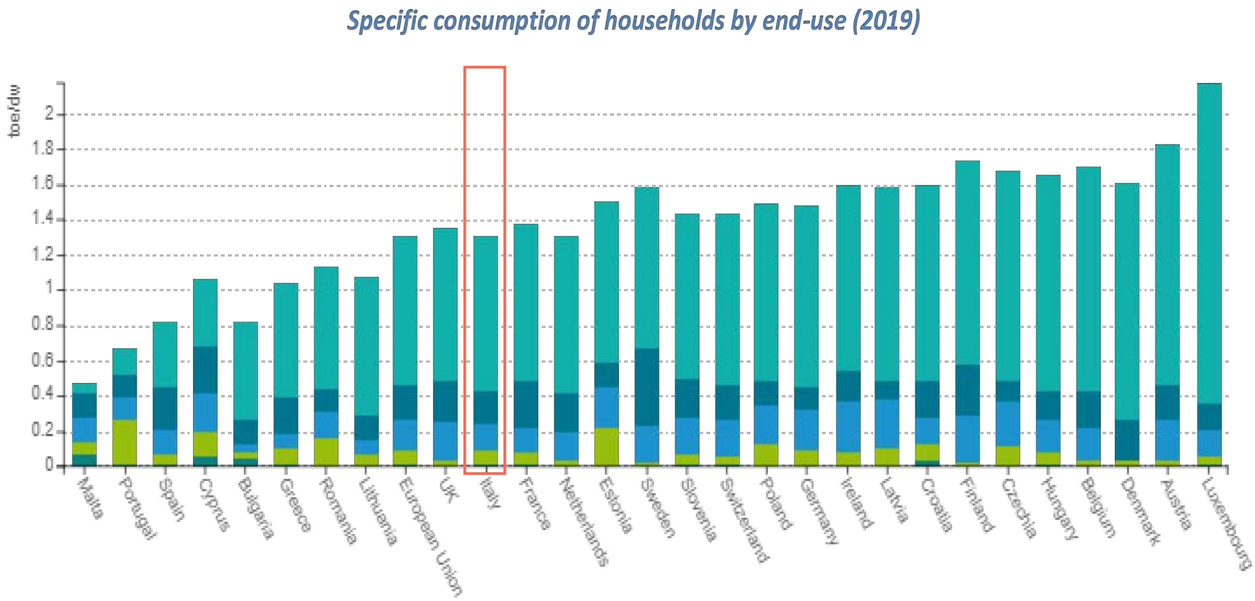
The big leap happened in the period between 2008 and 2014. There is practically no variation between 2014-and 2019:

Variation of average consumption per dwelling (at normal climate)



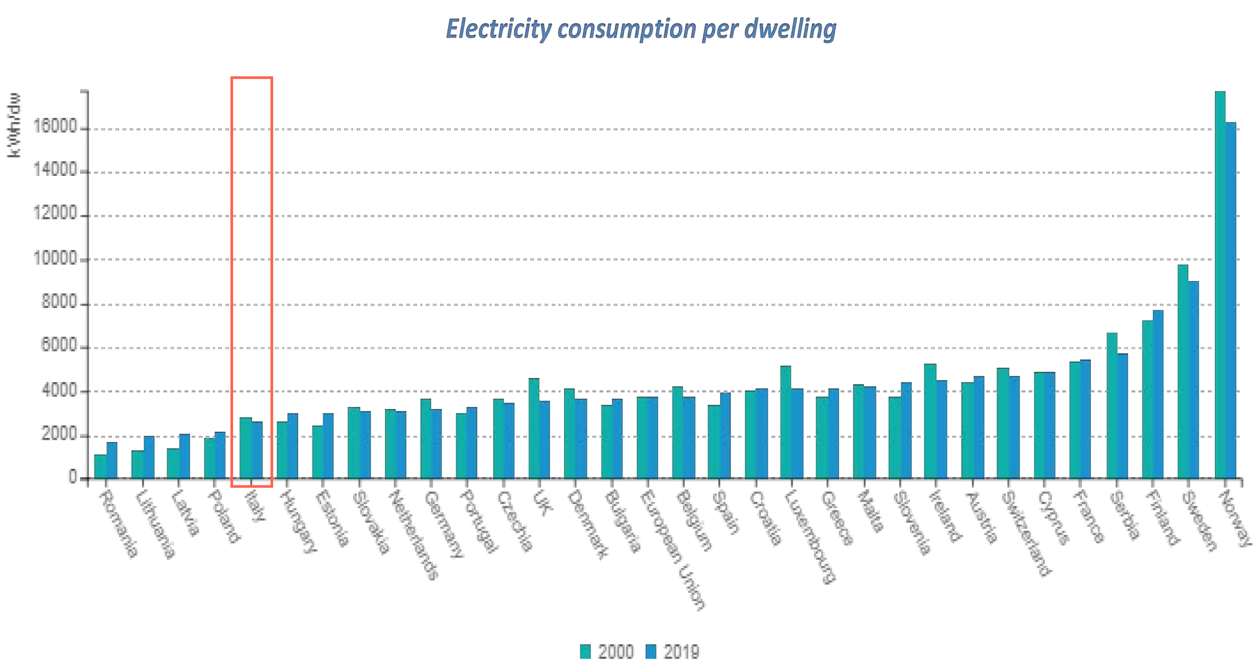
Source: ODYSSEE-MURE, Sectorial energy profile - Households

Around 70% of energy consumption is used on space heating:



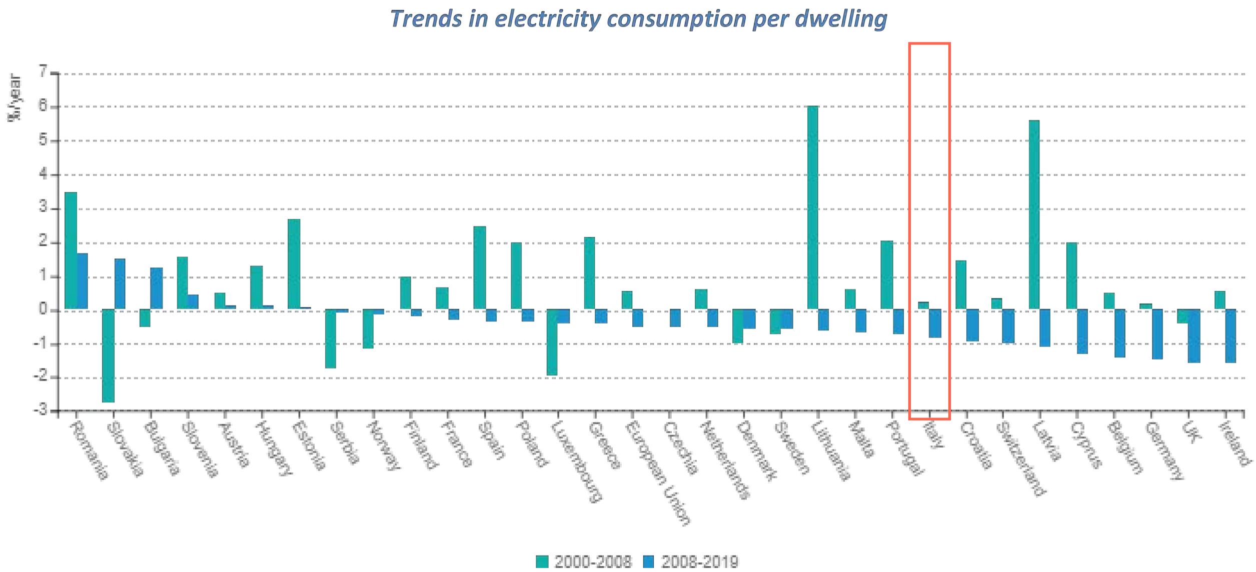
Source: ODYSSEE-MURE, Sectorial energy profile - Households

Electricity consumption has decreased very slightly between 2000 and 2019:



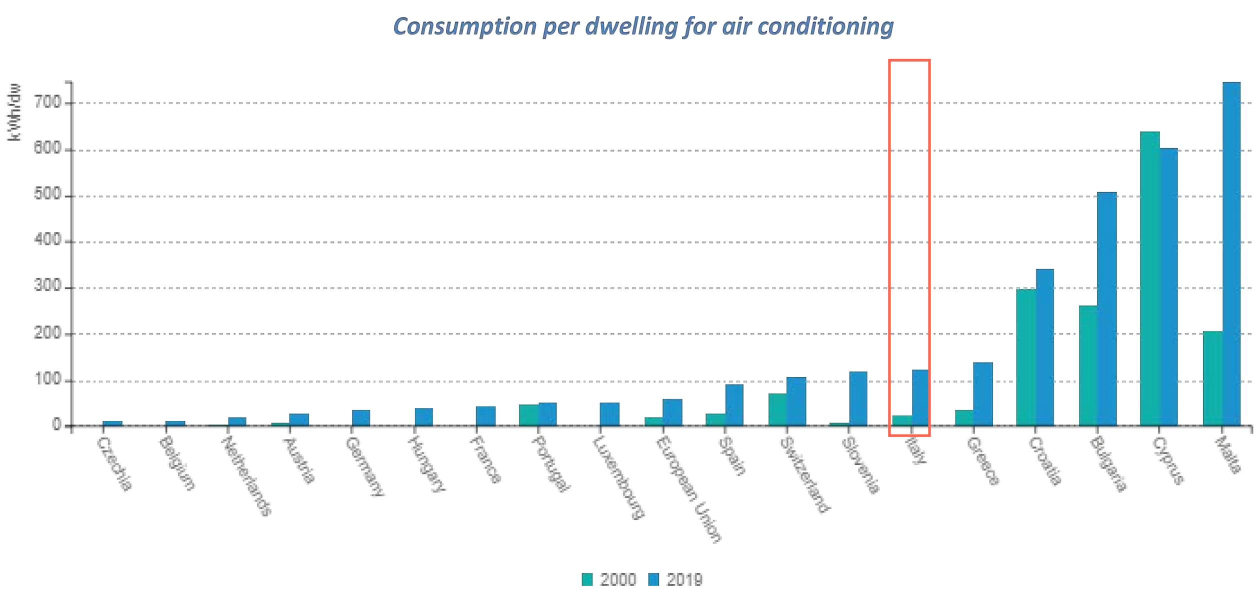
Source: ODYSSEE-MURE, Sectorial energy profile - Households

By period, electricity consumption decrease has been between 2009 and 2019:



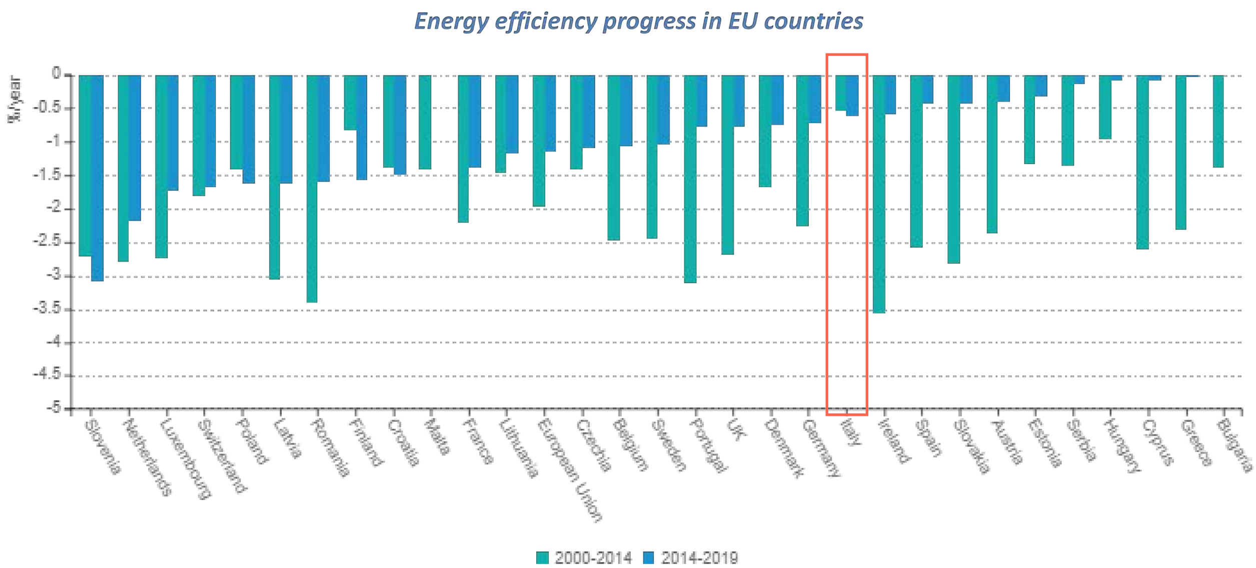
Source: ODYSSEE-MURE, Sectorial energy profile - Households

In 2019 air conditioning has risen around 5 times compared to 2000:



Source: ODYSSEE-MURE, Sectorial energy profile - Households

Energy efficiency has decreased between 2014-2019 compared to 2000-2014:



Source: ODYSSEE-MURE, Sectorial energy profile - Households

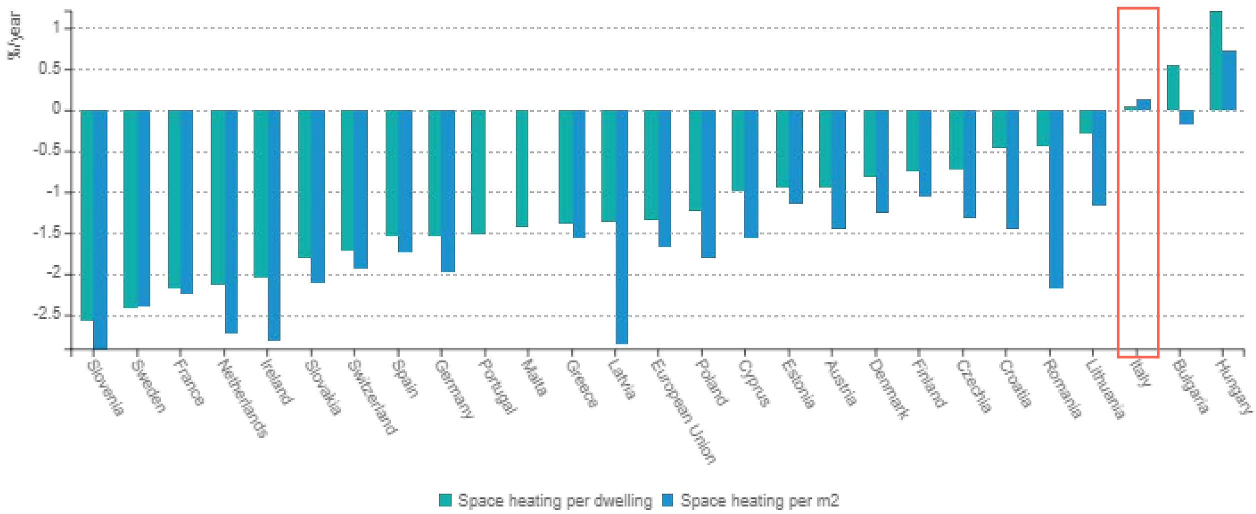
Without climate adjustment (a calculation made by ODYSSEE-MURE) therefore at normal climate, the residential energy matrix in 2019 was composed by gas 52,1%, wood 20,4%, electricity 18,2%, oil 6,4% and Heat 2,9%

RESIDENTIAL CONSUMPTION					
	MTOE	KWH	KWH/M2	%	%
OIL	1,98	23027399943	9,60799477720027	6,39534883729327	6,4
GAS	16,13	187591899533	78,2711897747727	52,099483204082	52,1
HEAT	0,89	10350699974	4,31874512696733	2,87467700251652	2,9
WOOD	6,32	73501599817	30,6679429247624	20,4134366924799	20,4
ELECTRICITY	5,64	65593199837	27,368227546911	18,2170542636283	18,2
	30,96	360064799104	150,234100150614	100	100

Source: ODYSSEE-MURE Database

Space heating by dwelling and by square meter is very similar and has increased comparing 2000 and 2019, but by square meter is more than double, which means that in Italy households are becoming smaller:

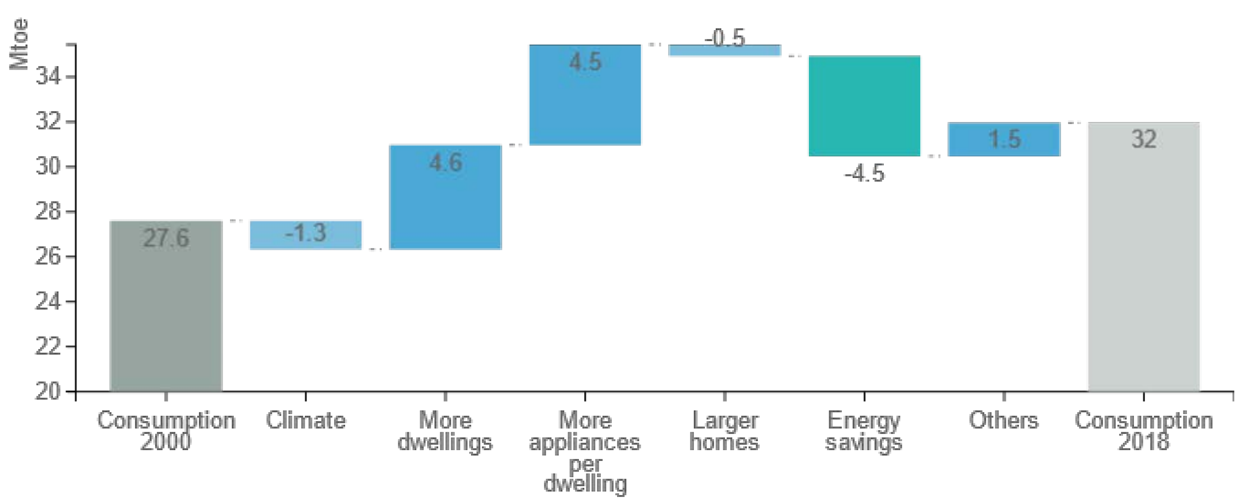
Variation of consumption per m² VS per dwelling: effect of change in dwelling size (2000-2019)



Source: ODYSSEE-MURE, Sectorial energy profile - Households

In Italy, the main drivers of increased consumption are the increase in dwellings and the increase on appliances per dwelling.

Main drivers of the energy consumption variation of households



Source: ODYSSEE-MURE, Italy energy profile, March 2021

These analyses made by the ODYSSEE-MURE project are very important for the development of a localized strategy that will accelerate the renovation depth of households, as it is now very clear how the energy is used. It is not possible to reduce energy consumption if it is not understood how much and in which way the energy is used.

4.4) Wind turbines and solar photovoltaic panels potential

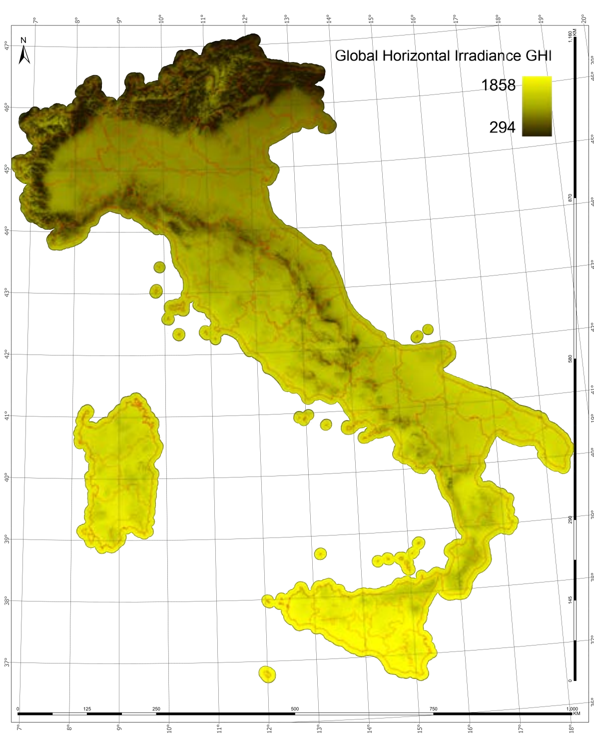
Even if there are many renewable energy alternatives, there is little to no doubt that the most mature in terms of technology development is hydropower. For around a century it has been implemented around the world and turbines have evolved into levels of efficiency in terms of price and energy production that even allow very small projects to be worthy of the investment. Horizontal turbines on irrigation channels for example that can go as small of 5kW of installed power are a reality in thousands of farms and rural areas around the world. The big problem they have, hydropower energy generation in general, big or small, is what we are seeing more evidently in the last years: global warming. Drought is rapidly increasing worldwide and on many types of climate, temperatures are becoming more extreme and so by now, 2022, we can clearly understand how the climate categories defined by Köpenn are moving. Less snow on the mountains is equal to less water on the rivers and less rotation on hydropower turbines, specially smaller ones, therefore less energy production and therefore less returns on the investments, which in turn are becoming more risky as uncertainty about the weather continues to rise. Nowadays we can't in most cases responsibly plan hydropower plants, that usually last for 50+ years, because the amount of cubic meters that in the future will flow through a river it is in most cases uncertain. What is certain though, is solar radiation and the speed of the wind, as they are unaffected by global warming. Solar and wind power are also the second and third more mature renewable energy technologies available, which translates to better panels in the case of solar, and better turbines in the case of wind. Solar has seen a significant evolution over the last few decades. Wind most specially in the last few of years, making it in most cases the cheaper source of renewable energy. A recent renewables auction in the UK shows that in their country offshore wind energy is nine times cheaper than from fossil fuels[65]. Nine times cheaper. It is not a mystery to anyone that has knowledge on renewable energy production, operation and maintenance, that in the 21st century, eolic is the hydro of the 20th century. Not only the installed, operational and maintained kWh is cheaper to produce than solar panels. One turbine can usually produce the same as dozens of panels, which by the way need to be cleaned of dust at least twice a week and therefore require more employees for the daily operation. The amount will depend obviously on the size of the solar farm, but being conservative at the very least there will be needed 2 persons on a full time job just to clean the panels. On the other hand, and same as a small hydropower plant, a wind power plant can operate with just 3 persons in total, that only need to be alert for when the generators or electrical production system crashes and therefore reboot the energy injection as fast as possible. Less salaries to pay and less humans around means less possibilities of human errors and better monthly earnings. In this sense the big difference of human resources needed is that for a wind turbine operation there is need of only two person to live on site,

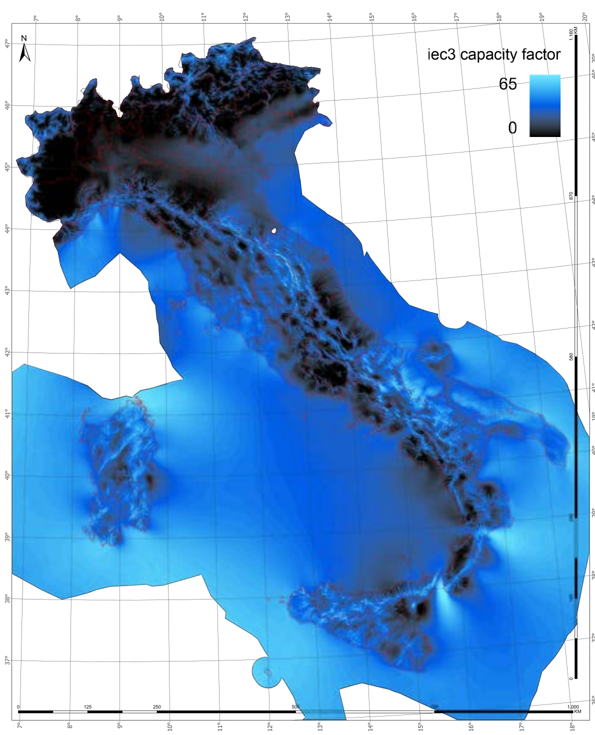
[65] NASDAQ, 2022

living at a 10-20 minute distance form the machines room, for when there is an urgency that requires a manual reboot, but 90% of the times the reboot can be done remotely through internet controllers. This advantage is only matched by small hydropower plants. If we add the improvements on technologies and prices, it is very clear that in the near future and around the world, wind power will become the favourite choice for renewable energy generation, while of course solar the second. Solar will still be around for many decades, because not only it makes more sense for smaller energy projects that have good solar radiation conditions, but also because sometimes wind speeds are just not enough for a wind turbine, and therefore it doesn't make any sense to invest on a wind turbine. As of 2022, other renewables such as geothermal, tidal, wave energy, etc are not even close to the capacity of solar or wind generation and therefore it is not serious to make a plan with technology that isn't competitive. Maybe in a few more decades some other renewable will gain momentum as their technology and efficiency develops but at the present realistically speaking there is no other renewable source that can compete with solar or wind.

Having clarified this, on this research the wind turbines and solar photovoltaic panels potential is analysed throughout the country, in order to establish on which regions and provinces it is a better choice one over the other.

This analysis starts by acknowledging that every country has different zones, for each technology, that will present better potential than others. This information can be easily accessed via the World Bank's energy atlases for wind and solar, that have the whole planet studied. For solar power potential the measurement is the global horizontal irradiance and for wind the International Electrotechnical Commission IEC category 3, IEC3, and its capacity factor. In both cases the higher the value, more energy will be produced. In the case of wind it is used the IEC3 instead of other classes, simply because as of 2022, the technology of IEC3 wind turbine rotors are the world most efficient in terms of price and energy production.





As mentioned earlier on the methodology explanation chapter, in Italy and as in many countries there are different regulations for energy projects under 5mW of installed power and over 5mW of installed power. Usually as in the case of Italy, a small power plant, under 5mW, is much easier to implement. From faster environmental impact assessments to cheaper energy distribution in both cases, auto consumption or connection to the national grid, to energy cooperatives incentives, to energy communities incentives and everything in between, there are always benefits to develop an under 5mW project. In terms of energy loss through the grid is also much more efficient to have many small projects throughout the territory than fewer bigger projects that usually ecologically sacrifice a specific place, loose energy along the distribution line and in terms of investment it would be impossible for a municipality or a group of municipalities to afford. As the case of this research is't producing profits to create fortunes but to allow municipalities to invest the profit on retrofitting their homes, the 5mW limit of installed power it is considered. A project of this size can in theory easily produce within the around 20 years of life of the turbine or solar panels, the income required for improving buildings and homes envelopes and so reducing their heat loss coefficients, improve the quality of life of the inhabitants, reduce their energy expenditures, increase resilience to global warming and extreme weather events such as heatwaves, and possibly even generate a surplus over that investment to then invest in public spaces that benefit everyone. The big questions are first what is the best technology to use and then how it is deployed in order to achieve the decarbonization goals within the timeframe to be in line with the national targets and pathways already explained at the beginning.

To calculate the return on investment for the different technologies, there are four variables that need to be known:

A) Installation cost in €
B) Yearly operation and maintenance cost in €
C) Amount of yearly energy produced in MWh
D) MWh price in €

As an equation for a ROI in 20 years, it would be:

$$ROI = (C \times 20 \times D) - (A + (B \times 20))$$

The compared results presented here, take in consideration the following variables.

4.4.a) Solar

Agro-PV, also called agrivoltaics, agrophotovoltaics or agrisolar within other denominations, it is a method of installing photovoltaic solar panels that allows agriculture on the same land as the panels. In the last decades there has been a lot of research on different countries such as Japan, the US and also in Italy, showing that not only agriculture can coexist with the panels, but it can also be improved. This means that the benefits of an agro-pv deployment is not only terms of produced energy, but also on food production, therefore the returns and benefits are more. As explained by Fraunhofer Institute for Solar Energy Systems ISE[66] there are many methods that can be implemented that will depend on the type of agricultural production the farm is producing or wants to produce, but they identify five categories of business model scenarios:

Business model	Function:			
	Providing land	Agricultural management	Providing the PV system	Operating the PV system
1-Base case	Farm			
2-External land ownership	Land owners	Farm		
3-External PV investment	Farm		PV investor	Farm
4-Cultivations and operation only	Land owners	Farm	PV investor	Farm
5-Cultivation only	Land owners	Farm	PV investor	PV operator

Without focusing on a single business model case and according to the Italian government's Ministry for the Ecological Transition MITE, on their June 2022 report about the guidelines for Italian agrovoltaics[67] it is stated that in Italy the installation cost of an 1MW APV system and that can be considered equal to solar farms of installed power between 750kW and 5MW, oscillates between €1.194/kW and €940/kW depending on the type of agriculture being performed on the soil; and the operation and maintenance O&M cost is in any scenario €16,3/kW per year. On the calculation for the ROI in the case of this research, it is considered the higher cost of installation, therefore €1.194/kW on 5MW is €5.970.000 installation cost and a yearly €81.500 cost for O&M. Considering 20 years, the total cost of Agro-PV in this case is therefore €8.415.000. Traditional solar photovoltaic panels installation denominated Ground-mounted PV are much cheaper. According to the same MITE document and same ranges just mentioned, it costs €748/kW for installation and €18,7/kW for O&M. Translating into a 5MW project the total cost for 20 years is therefore €5.610.000. As also mentioned, Agro-PV has the extra food production in terms of returns, as agriculture can thrive on the same soil, but indeed those returns depend on what type of agriculture is being carried on. For the case of this research and the comparison between systems, it is only considered the energy production in the case of injecting into the grid to provide energy for homes, but it is worth mentioning that in the case of a farm that desire to install panels to provide for its own electrical demands, returns would differ as the auto consumption of energy for their operations would translate into indirect returns as they will be saving on their energy bills. Regarding the amount of energy produced every year, undoubtedly it depends on the specific location and the specific solar photovoltaic technology implemented. There are different ways of estimating the amount of energy that can be produced. One is through complex calculations and equations that require to know the performance index of the specific system, the specific location's cumulative annual solar radiation, the peak power output of the specific panel, the actual surface of the installed system and the tested

66 Fraunhofer ISE, 2020
67 Ministero della Transizione Ecologica, 2022

irradiation on standard conditions of the panel that is being used, as explained in deep by Suri et.al (2007)[68]. This method should be performed when all the variables are known in order to granulate the results to a very realistic prediction specially at the moment of deciding which specific panel to install. Another realistic approach and the one used on this research, is based on the real national statistics of production, which in the case of Italy are provided yearly for each province by the GSE[69]. These statistics allow to predict estimates of possible production and so gather a realistic idea of the numbers before deciding which one of the hundreds of solar photovoltaic panels technology is actually going to be implemented. The method consist on dividing the production by the installed power, therefore resulting in the amount of effective hours: MWh / MW = h. Since GSE provides yearly statistics of this kind for each province of the country, and we want to compare the performance at 5MW on each province, it is possible to obtain the median numbers for the province. Obviously, as any statistical analysis that is based on the mean numbers it has to be acknowledged that there will be places inside a province that will have better or worse performance than the median depending on the specific topography and technology of panel used, but it is a valid indicator of comparison as it will be seen on the final output of the calculation.

4.4.b) Eolic

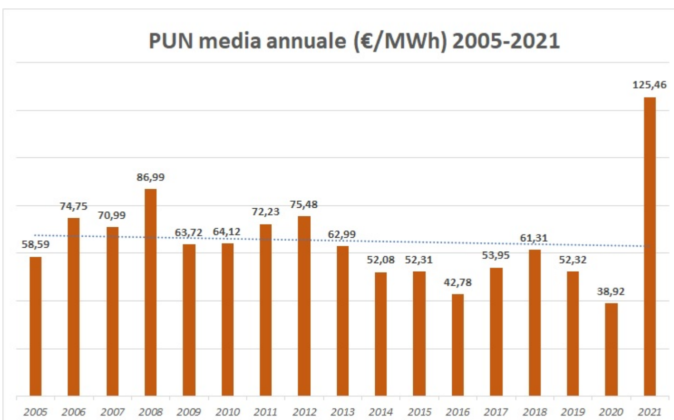
In Italy the regulation establishes that wind turbines must be located at a distance of at least 500 meters from the nearest home, therefore it is also considered on this research that the turbine(s) should be located on a farm outside the homes agglomerations. For this reason the same business models explained for solar farms, apply to wind plants. In terms of technology, as explained in earlier, it is chosen the Vestas turbine model V150-4,2MW, which has a median installation price in Italy of €3.430.770 and a median annual O&M cost of €40.000 for one turbine. Considering 20 years the total investment is €4.230.770 per turbine, almost half of an equivalent agro-pv installation. To calculate the energy production it is used the turbine's category (IEC3) capacity factor provided by the World Bank, also as explained earlier, that is geolocated. The method is that through GIS software, it is calculated the mean IEC3 capacity factor of the province and then the production calculation is performed. The calculation is 4.2 x 8760 x (capacity factor / 100). 4.2 is the maximum hourly output of the turbine, in this case 4.2MWh; 8760 is the yearly total amount of hours (24 x 365); and the capacity factor is the percentage of the yearly hours that the turbine will perform at 100%. Indeed it is an equivalence for calculating yearly production as in the case of any turbine they usually work at lower capacity than the maximum that they are designed for. As an example, a capacity factor of 10 means that this specific turbine would produce 4.2 x 8760 x 0.1 = 3,6792 GWh/year.

4.4.c) € / MWh price

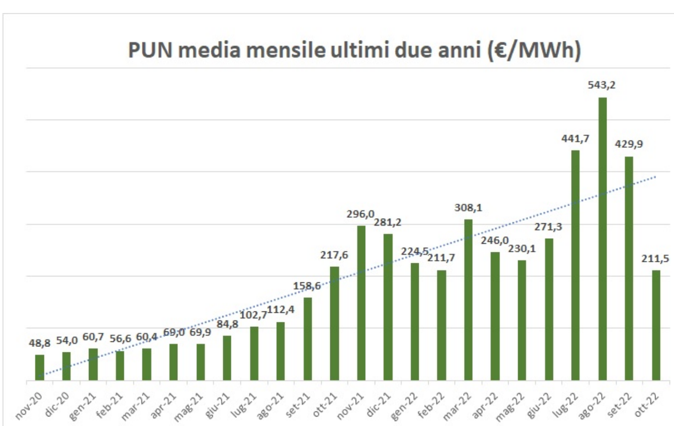
To calculate the returns and the payback time for the investment it is necessary to know the price for each MWh that is produced. In Italy the energy price changes

[68] Suri et al, 2007
[69] GSE, 2022b

everyday. It is measured though a free market value named PUN which price depends on a free open market regulated by supply and demand and administered by the GME (Gestori mercati energetici) which is the Italian power exchange. For renewable energy there are incentives that can be accessed by law which consist on fixed price in order to incentivise the investment. At the time of the writing of this research, the incentives are defined on the law DM 04/07/2019 that establishes that new photovoltaic and on-shore eolic, are part of the ‘Group A’, and as of 2022 the fixed price is 5% less of what is established on table 1.1 of annex 1 of that law document, which translates in 2022 to a 20 years fixed price of 66,5 €/MWh for installed power over 1MW in both the typologies analysed here. It is worth mentioning that at the time of writing of the current law, in 2019, this incentive was very good, since the annual median of the PUN was 61,31 €/MWh in 2018 and 52,32 €/MWh in 2019. Nowadays it is more convenient economically speaking to avoid the incentive and sell the energy directly on the open market, since in 2021 the average PUN was 125,46 €/MWh and in 2022 as of November, the yearly average so far, between January and October, is 311,8 €/MWh. The current year increase on the PUN is obviously because of the Russian war on Ukraine. A series of measures have been taken by the European Union and the Italian Government which has resulted in a reduction on the MWh price to around €110 in the first days of November 2022. There isn’t a clear consensus on the future price. Some analysts predict a stabilisation around €150/MWh and others around €200/MWh. But those predictions were made before the latest packages introduced by the EU in order to counter the current European energy crisis due to the lack of Russian gas. As seen in the last week of October and first days of November, it is probable that for the next few years the price is going to stabilise between 90 and 110 €/MWh. In this context, on this research two price scenarios are analysed: the first considering a price of €66,5/MWh, which is the current maximum price of the incentives and a second considering a price of €100/MWh, a conservative probable average of the MWh on the open market in the next twenty years.



Source: Qualenergia.it, 2022b

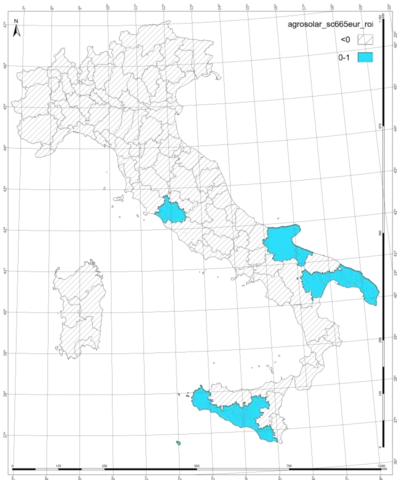


Source: Qualenergia.it, 2022a

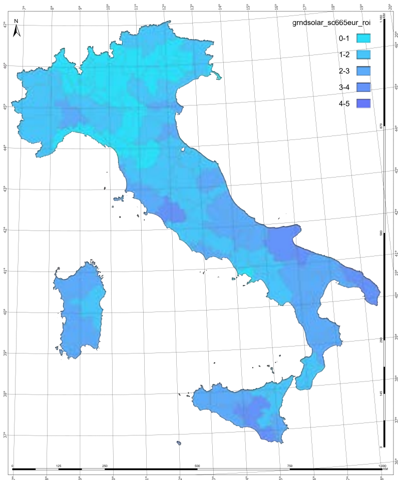
Considering the variables and scenarios just explained, the results are as follows. All maps use the same color symbology in €1M steps.

In the case the project obtains the current law incentive, a 20 year fixed price of 66.5 €/MWh, the return of investment in millions of euros, at the end of the 20th year is

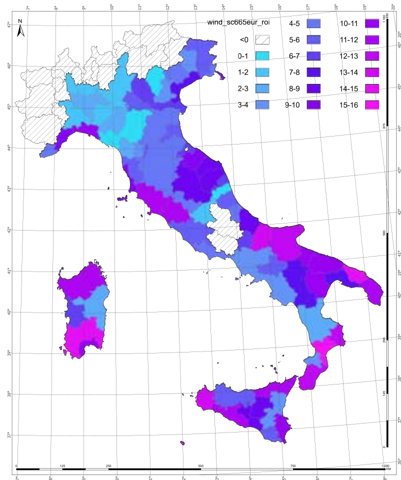
5MW Agro-PV
€66.5 €/MWh



5MW Ground-PV
€66.5 €/MWh



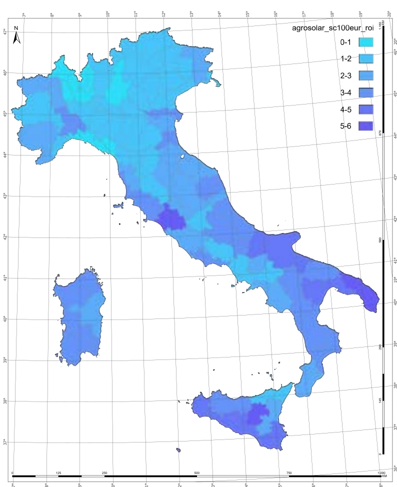
4.2MW IEC3 Wind turbine
€66.5 €/MWh



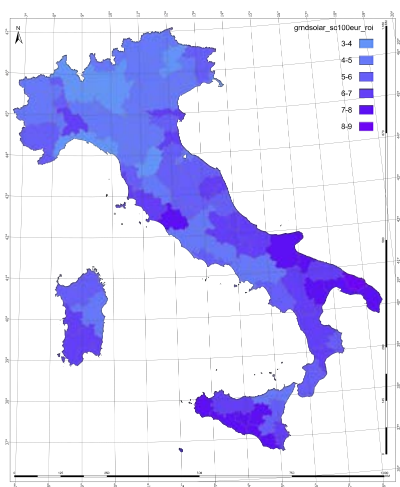
Hatched provinces don't manage to pay the investment. It can be seen that for Agro-PV after 20 years the returns would be under €1M on a few provinces; Ground-PV returns range between €0,01M and up to under €5M; a single wind turbine can get returns on most regions oscillating between €0,01M and up to under €16M.

In the case the project sells the produced energy on the open market and the average in the next 20 years is €100/MWh, the returns on the investment after the 20th year would be

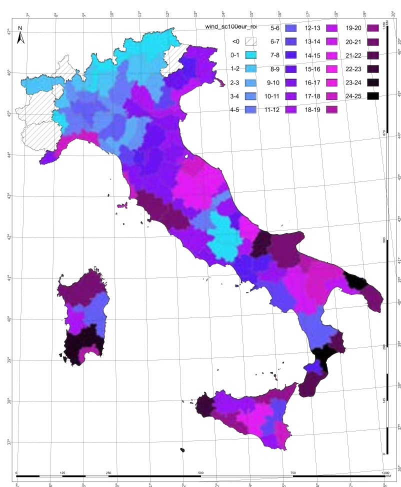
5MW Agro-PV
€100 €/MWh



5MW Ground-PV
€100 €/MWh



4.2MW IEC3 Wind turbine
€100 €/MWh



We can see on this price scenario that on both solar types all regions get returns by the 20th year, but the wind turbine still doesn't on a few provinces. Returns oscillate in the case of Agro-PV between €0,01M and up to under €6M; Ground-PV between €5M-€6M and up to under €9M; on provinces that get returns, a wind turbine generates from €0,01M up to under €25M.

As a general conclusion about the potential of the technologies compared, it is a good finding that throughout the country Ground-PV is economically theoretically feasible on all provinces; that Agro-PV if we would consider the returns from the agriculture production would also be producing returns on most of them, but is an alternative that should be analysed farm by farm; and that throughout most of the country wind outperforms solar considerably, in some provinces up to roughly three times. Indeed each technology has its advantages and disadvantages and therefore decisions on technology should be taken based on the local context when designing action plans.

4.5) Stranding Risk Analysis

Through the use of the CRREM tool in the way explained on the methodology and as it was already mentioned, it is possible to obtain the median risk of homes depreciation by province. This value called by CRREM as 'Discounted cost of excess emissions' DCOEE, represents the percentage of the market value of a home that is at risk of being lost yearly due to the climate change vulnerability. After obtaining the value from the tool applied on the samples as explained on the methodology, they are grouped by province and then the median value for the province is calculated. Afterwards, with a simple mathematical step function provinces are divided in five categories according to their mean value and so one a category is assigned to the province in concordance with its median number.

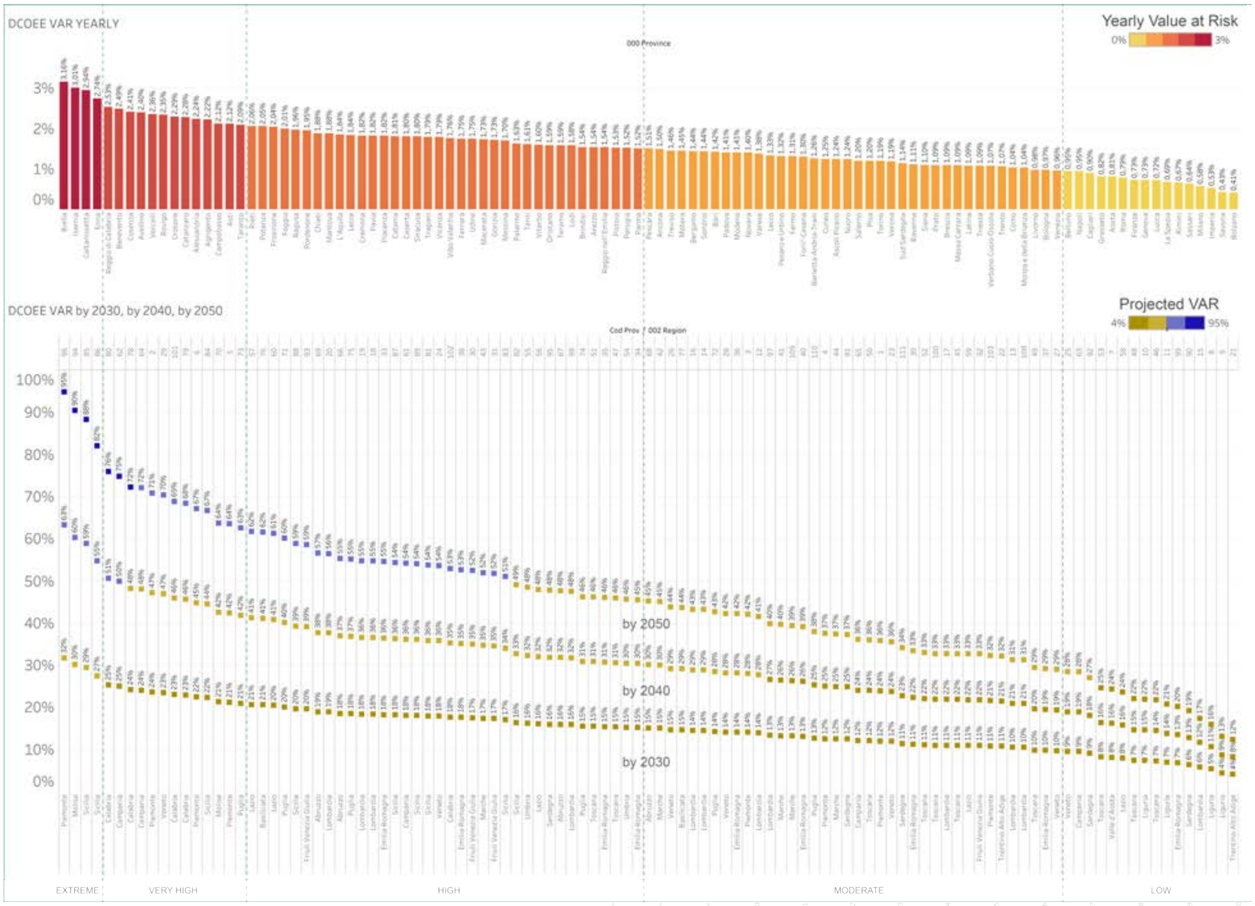
The defined 5 types of stranding risk are:

a) Extreme risk: up to 95% of home market value depreciation by 2050.
b) Very high risk: up to 76% of home market value depreciation by 2050.
c) High risk: up to 62% of home market value depreciation by 2050.
d) Moderate risk: up to 45% of home market value depreciation by 2050.
e) Low risk: up to 28% of home market value depreciation by 2050.

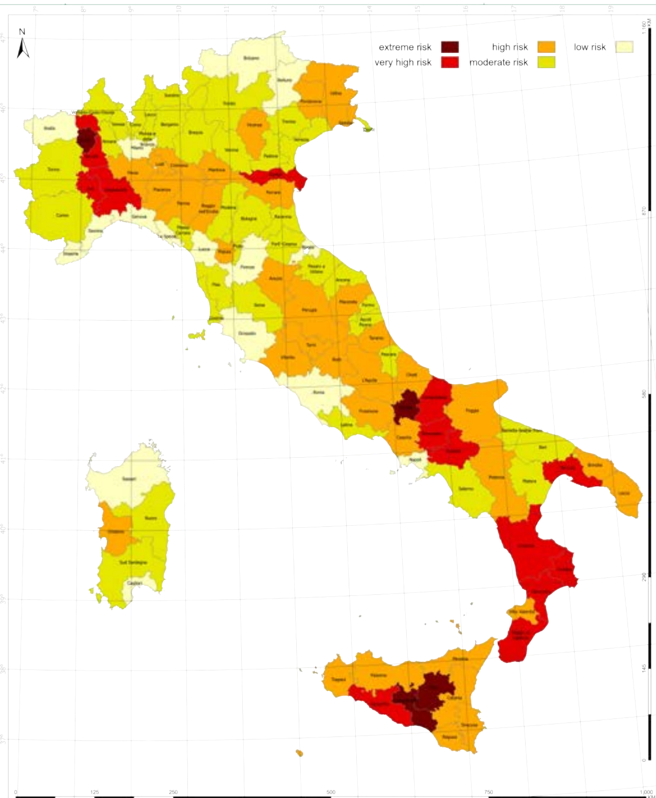
This categorization will be one of the main values used to calculate the vulnerability as it will be further explained on the vulnerability assessment.

Results show that out of the 107 provinces, the amount per category is:

Extreme risk:	4 provinces	3,7%
Very high risk:	13 provinces	12,1%
High risk:	36 provinces	33,6%
Moderate risk:	38 provinces	35,5%
Low risk:	16 provinces	15,1%

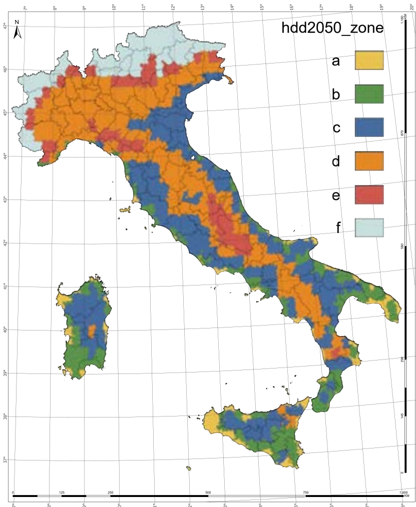


Both graphs and the map show the final categorization. On the first graph it can be seen that the output mean value for the specific province from the CRREM tool oscillates between 0,41% and 3,16% which represents the projection of the tool starting in 2020 since latest energy data is from 2019. On the second graph it can be seen the projection of that percentage starting on the year 2020 and by 2030, 2040 and 2050. Through the software Tableau a mathematical step function on the projected VAR is performed. Results are between 4% and 95%, therefore categories change every 18,2%. Extreme risk between 76,1% and 95%, Very high risk between 58,6% and 76,1%, High risk between 40,4% and 58,6%, Moderate risk between 22,2% and 40,4%, Low risk between 4% and 22,2% of market value depreciation of a home by 2050.

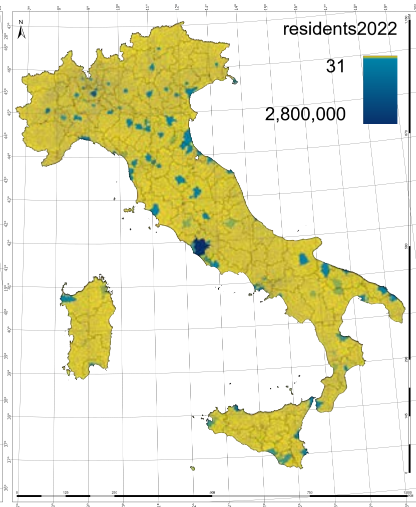


4.6) Vulnerability

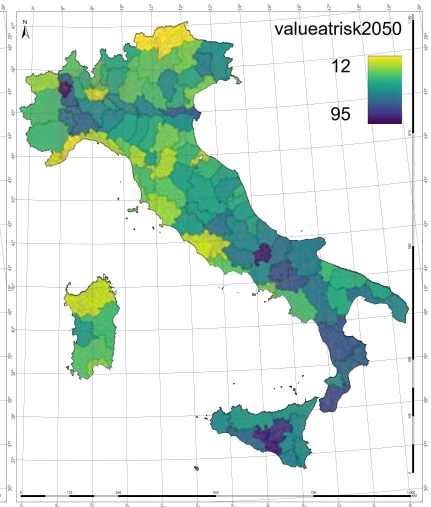
The three variables considered are the climate zone a municipality will be on by 2050, the amount of resident population and the stranding risk results.



CZ50 Climate zone in 2050



RP22 Resident Population Jan.2022.

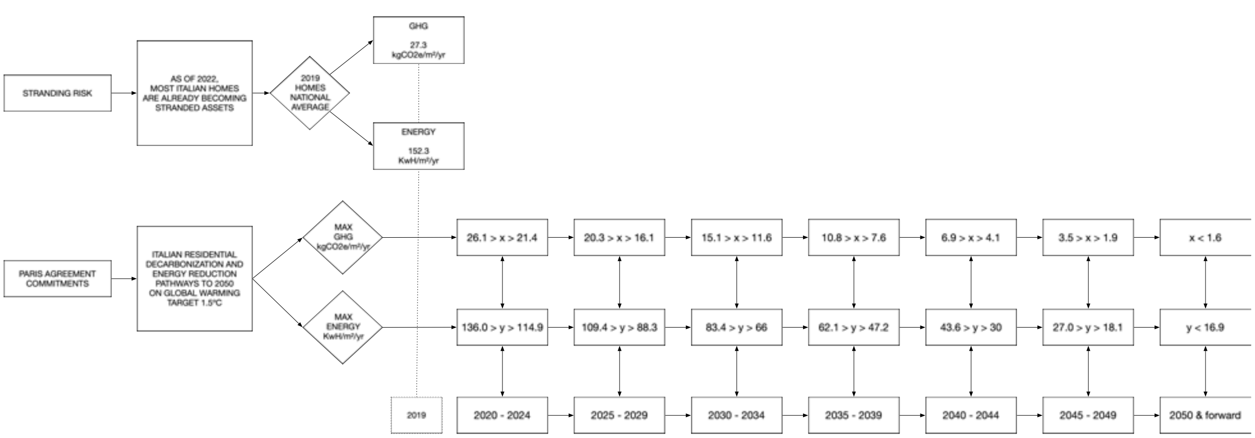


VAR50. Stranding risk projected VAR to 2050

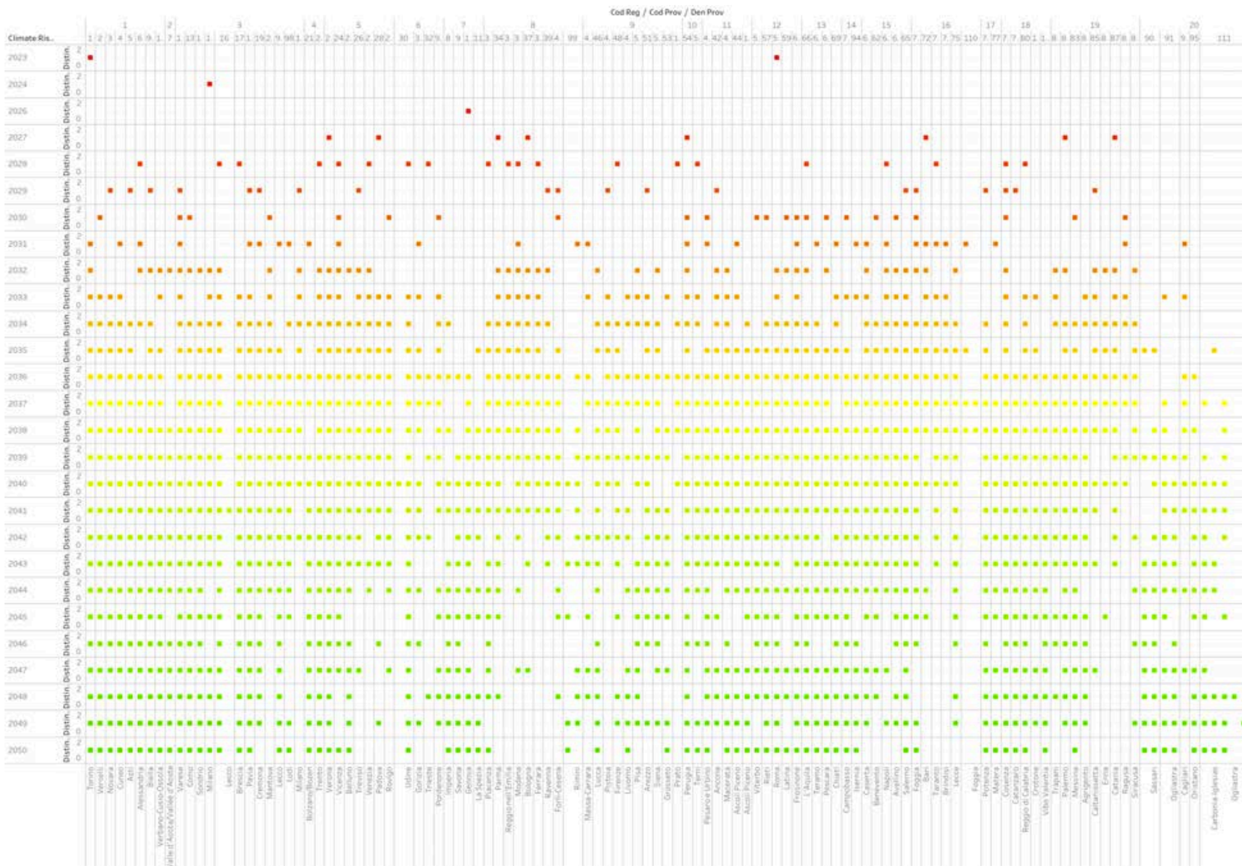
Assigning a risk value to each climate zone, in this case from A to F to 1 to 6 and multiplying it with the resident population and the projected VAR to 2050 from the stranding risk analysis, it is obtained an indicator, the climate risk.

$$CZ50 \times RP22 \times VAR50 = \text{Climate risk}$$

It should be acknowledged that the stranding risk results of this analysis are by province. The obtained granularity is by municipality as each received the stranding value of its province. The results were divided in 28 categories, one per each year between 2022 and 2050 therefore each municipality gets a different result as all have different resident population. The yearly categorization helps to organise action plans by risk priority. Plans in any case should also consider the established energy consumption and greenhouse gases pathway to a net-zero 2050, as a way to align the retrofit interventions with the national targets.



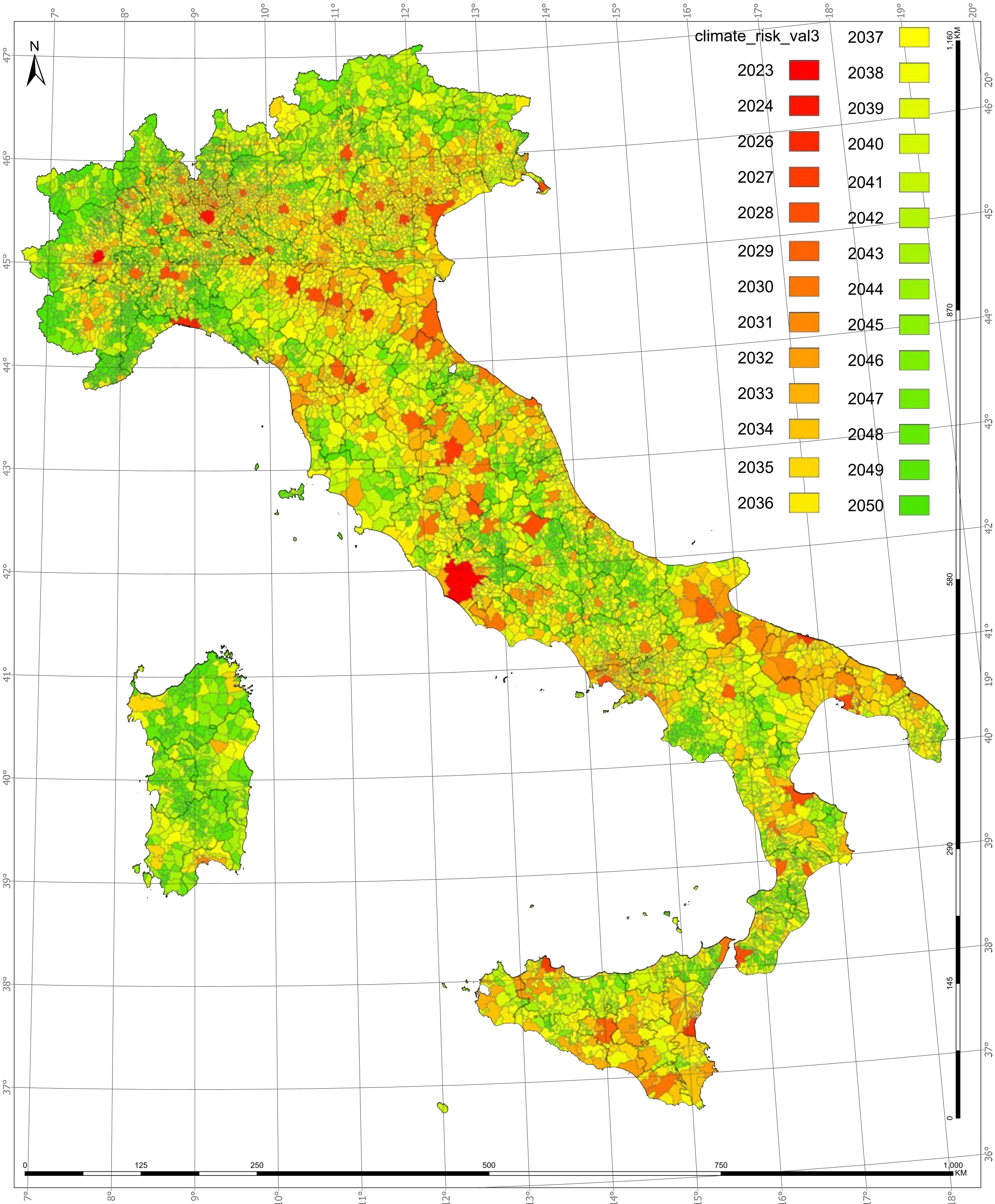
Results are displayed as a graph and in a map. Both use the same data and color graduation which starts from red for the year 2023, green by 2050 and through yellow between around 2035 an 2038.



On the graph each row is one of the 28 years between 2023 and 2050, the columns are each province by region and the dots represent a municipality. It can clearly by established the urgency certain municipalities face, but at the same time how a province and region can plan accordingly with the timings they have. It is reasonable to conclude according with the results that there is a need of urgency by 2030 on 76 municipalities, in descending order Roma, Torino, Milano, Genova by 2026, 64 others by 2030. The remaining 7828 within 2031 and 2050.

On the map we can visualise that many of the main agglomerations of primary homes reappear within the 2023-2030 period. This is expected as the resident population is one of the three factors. It also shows that agglomeration doesn’t mean higher risk, as for example the Napoli area even being one the more dense it has smaller grade of risk than the other big cities.

The two vulnerability questions that this research was aiming to answer are clear through the data generated from this climate risk indicator. In terms of how the risk spreads around the country, it is clear that the amount of population will always be an important factor, that the stranding risk is still mostly manageable and therefore there is time to implement action plans according to each local context, and that the appenine mountains areas throughout the country are more exposed to climate risks. Looking on the details of the administrative subdivisions, it can also be noted that not all provinces face the same challenges, but indeed all will have to be decarbonised by mid century. Greener areas on the map are the ones more resilient to the decarbonization transition risks because their homes are less agglomerated and their market value outruns the risk for a couple of decades relatively still. In terms of the second question about which areas should be prioritised, the year categorization allows to rate the vulnerability and therefore action plans should consider taking action on those municipalities before others that can safely wait more years.

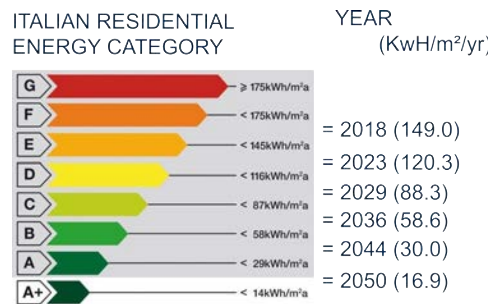


Climate Re..	Grand Total	1	2	3	4	5	6	7	8	9	10
Grand Total	Homes: 30.996.215 Total energy need for homes: 161,925 GWh/yr Solar installed power needed: 158,188 MW Turbines needed: 45,101	Homes: 2.444.703 Total energy need for homes: 19,276 GWh/yr Solar installed power needed: 18,947 MW Turbines needed: 13,862	Homes: 117.293 Total energy need for homes: 2,241 GWh/yr Solar installed power needed: 2,121 MW Turbines needed: 761	Homes: 4.796.718 Total energy need for homes: 33,509 GWh/yr Solar installed power needed: 36,233 MW Turbines needed: 10,658	Homes: 547.514 Total energy need for homes: 7,511 GWh/yr Solar installed power needed: 7,598 MW Turbines needed: 2,916	Homes: 2.378.774 Total energy need for homes: 15,332 GWh/yr Solar installed power needed: 15,367 MW Turbines needed: 4,442	Homes: 676.864 Total energy need for homes: 4,432 GWh/yr Solar installed power needed: 4,347 MW Turbines needed: 669	Homes: 1.072.491 Total energy need for homes: 5,099 GWh/yr Solar installed power needed: 5,494 MW Turbines needed: 764	Homes: 2.315.382 Total energy need for homes: 12,184 GWh/yr Solar installed power needed: 11,848 MW Turbines needed: 2,446	Homes: 1.891.554 Total energy need for homes: 9,073 GWh/yr Solar installed power needed: 8,984 MW Turbines needed: 1,347	Homes: 446.415 Total energy need for homes: 2,686 GWh/yr Solar installed power needed: 2,502 MW Turbines needed: 335
2023	Homes: 1.708.327 Total energy need for homes: 7,704 GWh/yr Solar installed power needed: 7,450 MW Turbines needed: 3,243	Homes: 448.678 Total energy need for homes: 2,928 GWh/yr Solar installed power needed: 2,904 MW Turbines needed: 2,653									
2024	Homes: 643.053 Total energy need for homes: 3,726 GWh/yr Solar installed power needed: 4,124 MW Turbines needed: 1,013			Homes: 643.053 Total energy need for homes: 3,726 GWh/yr Solar installed power needed: 4,124 MW Turbines needed: 1,013							
2026	Homes: 309.700 Total energy need for homes: 1,837 GWh/yr Solar installed power needed: 2,071 MW Turbines needed: 263							Homes: 309.700 Total energy need for homes: 1,837 GWh/yr Solar installed power needed: 2,071 MW Turbines needed: 263			
2027	Homes: 1.169.154 Total energy need for homes: 4,545 GWh/yr Solar installed power needed: 4,331 MW Turbines needed: 656					Homes: 222.544 Total energy need for homes: 1,356 GWh/yr Solar installed power needed: 1,356 MW Turbines needed: 210			Homes: 301.212 Total energy need for homes: 1,570 GWh/yr Solar installed power needed: 1,554 MW Turbines needed: 259		Homes: 73.911 Total energy need for homes: 450 GWh/yr Solar installed power needed: 423 MW Turbines needed: 60
2028	Homes: 1.829.564 Total energy need for homes: 8,638 GWh/yr Solar installed power needed: 8,553 MW Turbines needed: 1,813	Homes: 46.662 Total energy need for homes: 272 GWh/yr Solar installed power needed: 234 MW Turbines needed: 62		Homes: 158.957 Total energy need for homes: 1,042 GWh/yr Solar installed power needed: 1,104 MW Turbines needed: 351	Homes: 58.190 Total energy need for homes: 593 GWh/yr Solar installed power needed: 613 MW Turbines needed: 230	Homes: 191.379 Total energy need for homes: 1,027 GWh/yr Solar installed power needed: 1,031 MW Turbines needed: 211	Homes: 166.206 Total energy need for homes: 952 GWh/yr Solar installed power needed: 962 MW Turbines needed: 104		Homes: 299.707 Total energy need for homes: 1,576 GWh/yr Solar installed power needed: 1,562 MW Turbines needed: 394	Homes: 252.479 Total energy need for homes: 1,217 GWh/yr Solar installed power needed: 1,261 MW Turbines needed: 161	Homes: 53.999 Total energy need for homes: 339 GWh/yr Solar installed power needed: 307 MW Turbines needed: 35
2029	Homes: 926.433 Total energy need for homes: 4,818 GWh/yr Solar installed power needed: 4,596 MW Turbines needed: 1,031	Homes: 110.938 Total energy need for homes: 738 GWh/yr Solar installed power needed: 748 MW Turbines needed: 315		Homes: 201.282 Total energy need for homes: 1,175 GWh/yr Solar installed power needed: 1,255 MW Turbines needed: 332		Homes: 40.916 Total energy need for homes: 238 GWh/yr Solar installed power needed: 240 MW Turbines needed: 45			Homes: 152.553 Total energy need for homes: 623 GWh/yr Solar installed power needed: 540 MW Turbines needed: 83	Homes: 90.646 Total energy need for homes: 591 GWh/yr Solar installed power needed: 574 MW Turbines needed: 77	
2030	Homes: 807.854 Total energy need for homes: 3,829 GWh/yr Solar installed power needed: 3,569 MW Turbines needed: 741	Homes: 23.681 Total energy need for homes: 144 GWh/yr Solar installed power needed: 133 MW Turbines needed: 49		Homes: 106.600 Total energy need for homes: 679 GWh/yr Solar installed power needed: 742 MW Turbines needed: 197		Homes: 45.404 Total energy need for homes: 327 GWh/yr Solar installed power needed: 307 MW Turbines needed: 88	Homes: 25.619 Total energy need for homes: 154 GWh/yr Solar installed power needed: 156 MW Turbines needed: 26		Homes: 43.578 Total energy need for homes: 183 GWh/yr Solar installed power needed: 165 MW Turbines needed: 25		Homes: 26.122 Total energy need for homes: 168 GWh/yr Solar installed power needed: 158 MW Turbines needed: 22
2031	Homes: 1.133.251 Total energy need for homes: 5,830 GWh/yr Solar installed power needed: 5,506 MW Turbines needed: 1,754	Homes: 168.696 Total energy need for homes: 1,111 GWh/yr Solar installed power needed: 1,053 MW Turbines needed: 765		Homes: 108.677 Total energy need for homes: 687 GWh/yr Solar installed power needed: 743 MW Turbines needed: 196	Homes: 48.649 Total energy need for homes: 569 GWh/yr Solar installed power needed: 562 MW Turbines needed: 221	Homes: 35.470 Total energy need for homes: 282 GWh/yr Solar installed power needed: 284 MW Turbines needed: 102	Homes: 19.614 Total energy need for homes: 120 GWh/yr Solar installed power needed: 124 MW Turbines needed: 20		Homes: 120.181 Total energy need for homes: 584 GWh/yr Solar installed power needed: 572 MW Turbines needed: 118	Homes: 37.214 Total energy need for homes: 201 GWh/yr Solar installed power needed: 231 MW Turbines needed: 42	Homes: 39.733 Total energy need for homes: 257 GWh/yr Solar installed power needed: 241 MW Turbines needed: 34
2032	Homes: 1.637.920 Total energy need for homes: 8,522 GWh/yr Solar installed power needed: 8,246 MW Turbines needed: 2,693	Homes: 137.455 Total energy need for homes: 1,068 GWh/yr Solar installed power needed: 1,062 MW Turbines needed: 857	Homes: 18.496 Total energy need for homes: 345 GWh/yr Solar installed power needed: 326 MW Turbines needed: 117	Homes: 228.846 Total energy need for homes: 1,532 GWh/yr Solar installed power needed: 1,677 MW Turbines needed: 523	Homes: 19.350 Total energy need for homes: 195 GWh/yr Solar installed power needed: 201 MW Turbines needed: 76	Homes: 146.091 Total energy need for homes: 1,076 GWh/yr Solar installed power needed: 1,093 MW Turbines needed: 409			Homes: 135.250 Total energy need for homes: 705 GWh/yr Solar installed power needed: 678 MW Turbines needed: 141	Homes: 143.604 Total energy need for homes: 584 GWh/yr Solar installed power needed: 563 MW Turbines needed: 104	Homes: 17.104 Total energy need for homes: 104 GWh/yr Solar installed power needed: 98 MW Turbines needed: 14
2033	Homes: 1.678.928 Total energy need for homes: 7,213 GWh/yr Solar installed power needed: 6,959 MW Turbines needed: 1,690	Homes: 104.614 Total energy need for homes: 770 GWh/yr Solar installed power needed: 774 MW Turbines needed: 509		Homes: 181.544 Total energy need for homes: 1,128 GWh/yr Solar installed power needed: 1,218 MW Turbines needed: 345	Homes: 18.977 Total energy need for homes: 229 GWh/yr Solar installed power needed: 237 MW Turbines needed: 89	Homes: 141.745 Total energy need for homes: 759 GWh/yr Solar installed power needed: 751 MW Turbines needed: 128	Homes: 65.569 Total energy need for homes: 411 GWh/yr Solar installed power needed: 412 MW Turbines needed: 69		Homes: 96.420 Total energy need for homes: 506 GWh/yr Solar installed power needed: 498 MW Turbines needed: 115	Homes: 216.655 Total energy need for homes: 774 GWh/yr Solar installed power needed: 730 MW Turbines needed: 101	Homes: 33.672 Total energy need for homes: 184 GWh/yr Solar installed power needed: 171 MW Turbines needed: 23
2034	Homes: 2.474.712 Total energy need for homes: 12,162 GWh/yr Solar installed power needed: 11,831 MW Turbines needed: 3,123	Homes: 151.162 Total energy need for homes: 1,121 GWh/yr Solar installed power needed: 1,091 MW Turbines needed: 802		Homes: 387.738 Total energy need for homes: 2,477 GWh/yr Solar installed power needed: 2,706 MW Turbines needed: 753	Homes: 28.372 Total energy need for homes: 427 GWh/yr Solar installed power needed: 426 MW Turbines needed: 166	Homes: 261.169 Total energy need for homes: 1,556 GWh/yr Solar installed power needed: 1,551 MW Turbines needed: 408	Homes: 34.715 Total energy need for homes: 259 GWh/yr Solar installed power needed: 250 MW Turbines needed: 42	Homes: 25.891 Total energy need for homes: 141 GWh/yr Solar installed power needed: 131 MW Turbines needed: 27	Homes: 184.741 Total energy need for homes: 949 GWh/yr Solar installed power needed: 914 MW Turbines needed: 190	Homes: 265.587 Total energy need for homes: 1,239 GWh/yr Solar installed power needed: 1,229 MW Turbines needed: 202	Homes: 60.973 Total energy need for homes: 338 GWh/yr Solar installed power needed: 316 MW Turbines needed: 43
2035	Homes: 2.489.097 Total energy need for homes: 11,918 GWh/yr Solar installed power needed: 11,659 MW Turbines needed: 2,973	Homes: 106.045 Total energy need for homes: 774 GWh/yr Solar installed power needed: 771 MW Turbines needed: 547		Homes: 449.691 Total energy need for homes: 3,129 GWh/yr Solar installed power needed: 3,393 MW Turbines needed: 1,047	Homes: 3.470 Total energy need for homes: 45 GWh/yr Solar installed power needed: 47 MW Turbines needed: 18	Homes: 317.063 Total energy need for homes: 1,929 GWh/yr Solar installed power needed: 1,934 MW Turbines needed: 447	Homes: 64.406 Total energy need for homes: 401 GWh/yr Solar installed power needed: 391 MW Turbines needed: 66	Homes: 48.866 Total energy need for homes: 110 GWh/yr Solar installed power needed: 119 MW Turbines needed: 26	Homes: 148.293 Total energy need for homes: 765 GWh/yr Solar installed power needed: 752 MW Turbines needed: 168	Homes: 82.726 Total energy need for homes: 487 GWh/yr Solar installed power needed: 483 MW Turbines needed: 74	Homes: 12.238 Total energy need for homes: 71 GWh/yr Solar installed power needed: 67 MW Turbines needed: 9
2036	Homes: 2.651.945 Total energy need for homes: 12,866 GWh/yr Solar installed power needed: 12,528 MW Turbines needed: 3,223	Homes: 124.270 Total energy need for homes: 1,018 GWh/yr Solar installed power needed: 993 MW Turbines needed: 729		Homes: 439.406 Total energy need for homes: 2,777 GWh/yr Solar installed power needed: 2,997 MW Turbines needed: 841	Homes: 48.394 Total energy need for homes: 648 GWh/yr Solar installed power needed: 654 MW Turbines needed: 252	Homes: 247.090 Total energy need for homes: 1,557 GWh/yr Solar installed power needed: 1,556 MW Turbines needed: 379	Homes: 63.554 Total energy need for homes: 445 GWh/yr Solar installed power needed: 429 MW Turbines needed: 70	Homes: 99.940 Total energy need for homes: 275 GWh/yr Solar installed power needed: 281 MW Turbines needed: 40	Homes: 243.082 Total energy need for homes: 1,234 GWh/yr Solar installed power needed: 1,208 MW Turbines needed: 251	Homes: 191.357 Total energy need for homes: 939 GWh/yr Solar installed power needed: 929 MW Turbines needed: 126	Homes: 21.320 Total energy need for homes: 120 GWh/yr Solar installed power needed: 112 MW Turbines needed: 15
2037	Homes: 2.455.573 Total energy need for homes: 12,703 GWh/yr Solar installed power needed: 12,435 MW Turbines needed: 3,274	Homes: 117.511 Total energy need for homes: 920 GWh/yr Solar installed power needed: 898 MW Turbines needed: 636		Homes: 454.111 Total energy need for homes: 3,459 GWh/yr Solar installed power needed: 3,702 MW Turbines needed: 1,178	Homes: 19.035 Total energy need for homes: 239 GWh/yr Solar installed power needed: 241 MW Turbines needed: 93	Homes: 264.752 Total energy need for homes: 1,615 GWh/yr Solar installed power needed: 1,626 MW Turbines needed: 418	Homes: 83.929 Total energy need for homes: 445 GWh/yr Solar installed power needed: 432 MW Turbines needed: 71	Homes: 40.865 Total energy need for homes: 164 GWh/yr Solar installed power needed: 184 MW Turbines needed: 23	Homes: 158.596 Total energy need for homes: 853 GWh/yr Solar installed power needed: 826 MW Turbines needed: 173	Homes: 186.780 Total energy need for homes: 943 GWh/yr Solar installed power needed: 952 MW Turbines needed: 142	Homes: 21.501 Total energy need for homes: 146 GWh/yr Solar installed power needed: 136 MW Turbines needed: 18
2038	Homes: 1.964.062 Total energy need for homes: 10,620 GWh/yr Solar installed power needed: 10,420 MW Turbines needed: 3,005	Homes: 119.650 Total energy need for homes: 1,035 GWh/yr Solar installed power needed: 1,037 MW Turbines needed: 799	Homes: 2.849 Total energy need for homes: 53 GWh/yr Solar installed power needed: 50 MW Turbines needed: 18	Homes: 394.633 Total energy need for homes: 2,941 GWh/yr Solar installed power needed: 3,169 MW Turbines needed: 996	Homes: 25.975 Total energy need for homes: 340 GWh/yr Solar installed power needed: 351 MW Turbines needed: 132	Homes: 146.141 Total energy need for homes: 963 GWh/yr Solar installed power needed: 955 MW Turbines needed: 254	Homes: 27.668 Total energy need for homes: 204 GWh/yr Solar installed power needed: 194 MW Turbines needed: 33	Homes: 49.258 Total energy need for homes: 218 GWh/yr Solar installed power needed: 234 MW Turbines needed: 39	Homes: 155.870 Total energy need for homes: 870 GWh/yr Solar installed power needed: 850 MW Turbines needed: 180	Homes: 84.960 Total energy need for homes: 424 GWh/yr Solar installed power needed: 423 MW Turbines needed: 58	Homes: 20.775 Total energy need for homes: 122 GWh/yr Solar installed power needed: 114 MW Turbines needed: 15
2039	Homes: 1.692.647 Total energy need for homes: 9,979 GWh/yr Solar installed power needed: 9,804 MW Turbines needed: 3,085	Homes: 142.226 Total energy need for homes: 1,305 GWh/yr Solar installed power needed: 1,271 MW Turbines needed: 974	Homes: 9.934 Total energy need for homes: 178 GWh/yr Solar installed power needed: 169 MW Turbines needed: 61	Homes: 311.047 Total energy need for homes: 2,317 GWh/yr Solar installed power needed: 2,506 MW Turbines needed: 760	Homes: 56.362 Total energy need for homes: 774 GWh/yr Solar installed power needed: 788 MW Turbines needed: 301	Homes: 109.457 Total energy need for homes: 787 GWh/yr Solar installed power needed: 791 MW Turbines needed: 314	Homes: 28.801 Total energy need for homes: 248 GWh/yr Solar installed power needed: 237 MW Turbines needed: 39	Homes: 72.422 Total energy need for homes: 404 GWh/yr Solar installed power needed: 425 MW Turbines needed: 50	Homes: 106.470 Total energy need for homes: 636 GWh/yr Solar installed power needed: 623 MW Turbines needed: 129	Homes: 103.244 Total energy need for homes: 507 GWh/yr Solar installed power needed: 487 MW Turbines needed: 78	Homes: 16.491 Total energy need for homes: 94 GWh/yr Solar installed power needed: 87 MW Turbines needed: 12
2040	Homes: 1.204.208 Total energy need for homes: 7,194 GWh/yr Solar installed power needed: 7,029 MW Turbines needed: 1,996	Homes: 91.480 Total energy need for homes: 711 GWh/yr Solar installed power needed: 691 MW Turbines needed: 426	Homes: 15.805 Total energy need for homes: 295 GWh/yr Solar installed power needed: 279 MW Turbines needed: 100	Homes: 206.580 Total energy need for homes: 1,618 GWh/yr Solar installed power needed: 1,749 MW Turbines needed: 527	Homes: 32.856 Total energy need for homes: 523 GWh/yr Solar installed power needed: 528 MW Turbines needed: 203	Homes: 73.094 Total energy need for homes: 537 GWh/yr Solar installed power needed: 540 MW Turbines needed: 199	Homes: 36.798 Total energy need for homes: 265 GWh/yr Solar installed power needed: 253 MW Turbines needed: 43	Homes: 57.061 Total energy need for homes: 242 GWh/yr Solar installed power needed: 258 MW Turbines needed: 38	Homes: 67.365 Total energy need for homes: 459 GWh/yr Solar installed power needed: 453 MW Turbines needed: 92	Homes: 36.997 Total energy need for homes: 238 GWh/yr Solar installed power needed: 238 MW Turbines needed: 42	Homes: 14.672 Total energy need for homes: 86 GWh/yr Solar installed power needed: 80 MW Turbines needed: 10
2041	Homes: 1.004.282 Total energy need for homes: 6,130 GWh/yr Solar installed power needed: 5,967 MW Turbines needed: 1,944	Homes: 99.868 Total energy need for homes: 834 GWh/yr Solar installed power needed: 819 MW Turbines needed: 517	Homes: 11.382 Total energy need for homes: 267 GWh/yr Solar installed power needed: 253 MW Turbines needed: 91	Homes: 164.307 Total energy need for homes: 1,363 GWh/yr Solar installed power needed: 1,454 MW Turbines needed: 419	Homes: 30.986 Total energy need for homes: 522 GWh/yr Solar installed power needed: 526 MW Turbines needed: 203	Homes: 59.229 Total energy need for homes: 533 GWh/yr Solar installed power needed: 543 MW Turbines needed: 320	Homes: 19.946 Total energy need for homes: 128 GWh/yr Solar installed power needed: 126 MW Turbines needed: 21	Homes: 55.157 Total energy need for homes: 228 GWh/yr Solar installed power needed: 240 MW Turbines needed: 38	Homes: 31.221 Total energy need for homes: 199 GWh/yr Solar installed power needed: 194 MW Turbines needed: 38	Homes: 51.833 Total energy need for homes: 213 GWh/yr Solar installed power needed: 190 MW Turbines needed: 25	Homes: 7.193 Total energy need for homes: 42 GWh/yr Solar installed power needed: 39 MW Turbines needed: 5
2042	Homes: 714.321 Total energy need for homes: 4,602 GWh/yr Solar installed power needed: 4,478 MW Turbines needed: 1,431	Homes: 77.949 Total energy need for homes: 700 GWh/yr Solar installed power needed: 694 MW Turbines needed: 481	Homes: 11.832 Total energy need for homes: 228 GWh/yr Solar installed power needed: 216 MW Turbines needed: 77	Homes: 110.809 Total energy need for homes: 1,008 GWh/yr Solar installed power needed: 1,079 MW Turbines needed: 339	Homes: 29.928 Total energy need for homes: 481 GWh/yr Solar installed power needed: 485 MW Turbines needed: 187	Homes: 17.282 Total energy need for homes: 133 GWh/yr Solar installed power needed: 133 MW Turbines needed: 53	Homes: 9.966 Total energy need for homes: 109 GWh/yr Solar installed power needed: 103 MW Turbines needed: 17	Homes: 35.308 Total energy need for homes: 137 GWh/yr Solar installed power needed: 147 MW Turbines needed: 18	Homes: 12.470 Total energy need for homes: 81 GWh/yr Solar installed power needed: 77 MW Turbines needed: 16	Homes: 41.800 Total energy need for homes: 234 GWh/yr Solar installed power needed: 235 MW Turbines needed: 40	Homes: 10.364 Total energy need for homes: 54 GWh/yr Solar installed power needed: 50 MW Turbines needed: 6
2043	Homes: 479.989 Total energy need for homes: 3,454 GWh/yr Solar installed power needed: 3,358 MW Turbines needed: 1,180	Homes: 61.309 Total energy need for homes: 594 GWh/yr Solar installed power needed: 587 MW Turbines needed: 424	Homes: 749 Total energy need for homes: 14 GWh/yr Solar installed power needed: 13 MW Turbines needed: 5	Homes: 53.657 Total energy need for homes: 543 GWh/yr Solar installed power needed: 577 MW Turbines needed: 180	Homes: 42.598 Total energy need for homes: 634 GWh/yr Solar installed power needed: 637 MW Turbines needed: 246	Homes: 19.477 Total energy need for homes: 184 GWh/yr Solar installed power needed: 186 MW Turbines needed: 111	Homes: 5.431 Total energy need for homes: 47 GWh/yr Solar installed power needed: 44 MW Turbines needed: 8	Homes: 28.179 Total energy need for homes: 132 GWh/yr Solar installed power needed: 146 MW Turbines needed: 19	Homes: 20.568 Total energy need for homes: 139 GWh/yr Solar installed power needed: 136 MW Turbines needed: 25	Homes: 15.561 Total energy need for homes: 91 GWh/yr Solar installed power needed: 90 MW Turbines needed: 16	Homes: 6.863 Total energy need for homes: 46 GWh/yr Solar installed power needed: 43 MW Turbines needed: 6
2044	Homes: 399.521 Total energy need for homes: 2,583 GWh/yr Solar installed power needed: 2,503 MW Turbines needed: 957	Homes: 53.220 Total energy need for homes: 559 GWh/yr Solar installed power needed: 551 MW Turbines needed: 403	Homes: 11.467 Total energy need for homes: 217 GWh/yr Solar installed power needed: 205 MW Turbines needed: 74	Homes: 34.755 Total energy need for homes: 295 GWh/yr Solar installed power needed: 316 MW Turbines needed: 97	Homes: 16.507 Total energy need for homes: 241 GWh/yr Solar installed power needed: 244 MW Turbines needed: 94	Homes: 13.334 Total energy need for homes: 155 GWh/yr Solar installed power needed: 160 MW Turbines needed: 119	Homes: 4.779 Total energy need for homes: 44 GWh/yr Solar installed power needed: 43 MW Turbines needed: 7	Homes: 31.862 Total energy need for homes: 165 GWh/yr Solar installed power needed: 175 MW Turbines needed: 27	Homes: 11.807 Total energy need for homes: 89 GWh/yr Solar installed power needed: 88 MW Turbines needed: 21	Homes: 22.395 Total energy need for homes: 100 GWh/yr Solar installed power needed: 92 MW Turbines needed: 16	Homes: 2.538 Total energy need for homes: 15 GWh/yr Solar installed power needed: 14 MW Turbines needed: 2
2045	Homes: 227.157 Total energy need for homes: 1,608 GWh/yr Solar installed power needed: 1,556 MW Turbines needed: 571	Homes: 38.008 Total energy need for homes: 410 GWh/yr Solar installed power needed: 400 MW Turbines needed: 299		Homes: 21.320 Total energy need for homes: 205 GWh/yr Solar installed power needed: 219 MW Turbines needed: 70	Homes: 12.551 Total energy need for homes: 211 GWh/yr Solar installed power needed: 214 MW Turbines needed: 82	Homes: 1.838 Total energy need for homes: 15 GWh/yr Solar installed power needed: 15 MW Turbines needed: 5	Homes: 5.651 Total energy need for homes: 55 GWh/yr Solar installed power needed: 52 MW Turbines needed: 9	Homes: 22.496 Total energy need for homes: 106 GWh/yr Solar installed power needed: 114 MW Turbines needed: 16	Homes: 5.913 Total energy need for homes: 37 GWh/yr Solar installed power needed: 35 MW Turbines needed: 5	Homes: 9.481 Total energy need for homes: 54 GWh/yr Solar installed power needed: 53 MW Turbines needed: 7	Homes: 743 Total energy need for homes: 4 GWh/yr Solar installed power needed: 4 MW Turbines needed: 1
2046	Homes: 135.359 Total energy need for homes: 913 GWh/yr Solar installed power needed: 885 MW Turbines needed: 281	Homes: 15.927 Total energy need for homes: 127 GWh/yr Solar installed power needed: 129 MW Turbines needed: 83	Homes: 579 Total energy need for homes: 11 GWh/yr Solar installed power needed: 10 MW Turbines needed: 4	Homes: 20.953 Total energy need for homes: 185 GWh/yr Solar installed power needed: 197 MW Turbines needed: 65	Homes: 8.695 Total energy need for homes: 134 GWh/yr Solar installed power needed: 135 MW Turbines needed: 52	Homes: 5.027 Total energy need for homes: 40 GWh/yr Solar installed power needed: 41 MW Turbines needed: 18	Homes: 4.527 Total energy need for homes: 39 GWh/yr Solar installed power needed: 37 MW Turbines needed: 6	Homes: 4.307 Total energy need for homes: 27 GWh/yr Solar installed power needed: 27 MW Turbines needed: 3	Homes: 960 Total energy need for homes: 8 GWh/yr Solar installed power needed: 8 MW Turbines needed: 2	Homes: 6.758 Total energy need for homes: 36 GWh/yr Solar installed power needed: 35 MW Turbines needed: 6	Homes: 2.121 Total energy need for homes: 16 GWh/yr Solar installed power needed: 15 MW Turbines needed: 2
2047	Homes: 269.829 Total energy need for homes: 1,916 GWh/yr Solar installed power needed: 1,884 MW Turbines needed: 732	Homes: 45.395 Total energy need for homes: 437 GWh/yr Solar installed power needed: 433 MW Turbines needed: 312	Homes: 6.615 Total energy need for homes: 120 GWh/yr Solar installed power needed: 113 MW Turbines needed: 41	Homes: 32.891 Total energy need for homes: 356 GWh/yr Solar installed power needed: 379 MW Turbines needed: 132	Homes: 13.843 Total energy need for homes: 221 GWh/yr Solar installed power needed: 224 MW Turbines needed: 86	Homes: 7.659 Total energy need for homes: 94 GWh/yr Solar installed power needed: 97 MW Turbines needed: 62	Homes: 2.340 Total energy need for homes: 26 GWh/yr Solar installed power needed: 25 MW Turbines needed: 4	Homes: 28.791 Total energy need for homes: 106 GWh/yr Solar installed power needed: 110 MW Turbines needed: 12	Homes: 4.116 Total energy need for homes: 26 GWh/yr Solar installed power needed: 26 MW Turbines needed: 6	Homes: 13.780 Total energy need for homes: 62 GWh/yr Solar installed power needed: 60 MW Turbines needed: 11	Homes: 927 Total energy need for homes: 8 GWh/yr Solar installed power needed: 8 MW Turbines needed: 1
2048	Homes: 315.926 Total energy need for homes: 2,093 GWh/yr Solar installed power needed: 2,057 MW Turbines needed: 735	Homes: 43.616 Total energy need for homes: 424 GWh/yr Solar installed power needed: 422 MW Turbines needed: 308	Homes: 9.067 Total energy need for homes: 176 GWh/yr Solar installed power needed: 167 MW Turbines needed: 60	Homes: 37.225 Total energy need for homes: 378 GWh/yr Solar installed power needed: 404 MW Turbines needed: 125	Homes: 14.398 Total energy need for homes: 217 GWh/yr Solar installed power needed: 219 MW Turbines needed: 84	Homes: 3.622 Total energy need for homes: 48 GWh/yr Solar installed power needed: 50 MW Turbines needed: 38	Homes: 2.782 Total energy need for homes: 32 GWh/yr Solar installed power needed: 31 MW Turbines needed: 5	Homes: 38.381 Total energy need for homes: 166 GWh/yr Solar installed power needed: 178 MW Turbines needed: 25	Homes: 7.947 Total energy need for homes: 53 GWh/yr Solar installed power needed: 51 MW Turbines needed: 10	Homes: 12.964 Total energy need for homes: 42 GWh/yr Solar installed power needed: 41 MW Turbines needed: 7	Homes: 446 Total energy need for homes: 3 GWh/yr Solar installed power needed: 2 MW Turbines needed: 0
2049	Homes: 386.123 Total energy need for homes: 2,466 GWh/yr Solar installed power needed: 2,383 MW Turbines needed: 888	Homes: 60.773 Total energy need for homes: 609 GWh/yr Solar installed power needed: 603 MW Turbines needed: 420	Homes: 9.617 Total energy need for homes: 170 GWh/yr Solar installed power needed: 161 MW Turbines needed: 58	Homes: 24.511 Total energy need for homes: 232 GWh/yr Solar installed power needed: 249 MW Turbines needed: 78	Homes: 13.425 Total energy need for homes: 192 GWh/yr Solar installed power needed: 194 MW Turbines needed: 75	Homes: 7.346 Total energy need for homes: 106 GWh/yr Solar installed power needed: 111 MW Turbines needed: 93	Homes: 3.700 Total energy need for homes: 37 GWh/yr Solar installed power needed: 37 MW Turbines needed: 6	Homes: 45.536 Total energy need for homes: 233 GWh/yr Solar installed power needed: 239 MW Turbines needed: 36	Homes: 5.007 Total energy need for homes: 27 GWh/yr Solar installed power needed: 26 MW Turbines needed: 3	Homes: 17.623 Total energy need for homes: 79 GWh/yr Solar installed power needed: 71 MW Turbines needed: 11	Homes: 1.945 Total energy need for homes: 12 GWh/yr Solar installed power needed: 11 MW Turbines needed: 1
2050	Homes: 287.060 Total energy need for homes: 2,058 GWh/yr Solar installed power needed: 2,007 MW Turbines needed: 806	Homes: 55.570 Total energy need for homes: 670 GWh/yr Solar installed power needed: 650 MW Turbines needed: 492	Homes: 8.901 Total energy need for homes: 168 GWh/yr Solar installed power needed: 159 MW Turbines needed: 57	Homes: 24.125 Total energy need for homes: 255 GWh/yr Solar installed power needed: 272 MW Turbines needed: 95	Homes: 4.953 Total energy need for homes: 74 GWh/yr Solar installed power needed: 75 MW Turbines needed: 29	Homes: 1.645 Total energy need for homes: 18 GWh/yr Solar installed power needed: 19 MW Turbines needed: 10	Homes: 864 Total energy need for homes: 9 GWh/yr Solar installed power needed: 9 MW Turbines needed: 1	Homes: 78.471 Total energy need for homes: 408 GWh/yr Solar installed power needed: 415 MW Turbines needed: 64	Homes: 2.055 Total energy need for homes: 15 GWh/yr Solar installed power needed: 14 MW Turbines needed: 3	Homes: 7.110 Total energy need for homes: 17 GWh/yr Solar installed power needed: 15 MW Turbines needed: 3	Homes: 764 Total energy need for homes: 6 GWh/yr Solar installed power needed: 5 MW Turbines needed: 1

Climate Re..	Grand Total	11	12	13	14	15	16	17	18	19	Col Reg 20
Grand Total	Homes: 30.996.215 Total energy need for homes: 161,925 GWh/yr Solar installed power needed: 158,188 MW Turbines needed: 45,101	Homes: 773.922 Total energy need for homes: 3,496 GWh/yr Solar installed power needed: 3,066 MW Turbines needed: 428	Homes: 2.769.844 Total energy need for homes: 11,467 GWh/yr Solar installed power needed: 10,731 MW Turbines needed: 1,824	Homes: 764.967 Total energy need for homes: 4,291 GWh/yr Solar installed power needed: 3,602 MW Turbines needed: 960	Homes: 199.292 Total energy need for homes: 1,099 GWh/yr Solar installed power needed: 907 MW Turbines needed: 100	Homes: 2.440.365 Total energy need for homes: 8,328 GWh/yr Solar installed power needed: 8,135 MW Turbines needed: 1,224	Homes: 2.035.399 Total energy need for homes: 5,926 GWh/yr Solar installed power needed: 4,589 MW Turbines needed: 486	Homes: 322.244 Total energy need for homes: 1,694 GWh/yr Solar installed power needed: 1,420 MW Turbines needed: 160	Homes: 1.214.607 Total energy need for homes: 4,453 GWh/yr Solar installed power needed: 3,893 MW Turbines needed: 685	Homes: 2.861.795 Total energy need for homes: 7,220 GWh/yr Solar installed power needed: 6,140 MW Turbines needed: 800	Homes: 926.072 Total energy need for homes: 2,608 GWh/yr Solar installed power needed: 2,265 MW Turbines needed: 233
2023	Homes: 1.708.327 Total energy need for homes: 7,704 GWh/yr Solar installed power needed: 7,450 MW Turbines needed: 3,243		Homes: 1.259.649 Total energy need for homes: 4,776 GWh/yr Solar installed power needed: 4,547 MW Turbines needed: 590								
2024	Homes: 643.053 Total energy need for homes: 3,726 GWh/yr Solar installed power needed: 4,124 MW Turbines needed: 1,013										
2026	Homes: 309.700 Total energy need for homes: 1,837 GWh/yr Solar installed power needed: 2,071 MW Turbines needed: 263										
2027	Homes: 1.169.154 Total energy need for homes: 4,545 GWh/yr Solar installed power needed: 4,331 MW Turbines needed: 656						Homes: 140.982 Total energy need for homes: 474 GWh/yr Solar installed power needed: 389 MW Turbines needed: 40			Homes: 430.505 Total energy need for homes: 695 GWh/yr Solar installed power needed: 610 MW Turbines needed: 87	
2028	Homes: 1.629.564 Total energy need for homes: 8,638 GWh/yr Solar installed power needed: 8,553 MW Turbines needed: 1,813			Homes: 30.107 Total energy need for homes: 308 GWh/yr Solar installed power needed: 251 MW Turbines needed: 88		Homes: 361.966 Total energy need for homes: 668 GWh/yr Solar installed power needed: 675 MW Turbines needed: 98	Homes: 90.964 Total energy need for homes: 233 GWh/yr Solar installed power needed: 181 MW Turbines needed: 20		Homes: 118.948 Total energy need for homes: 411 GWh/yr Solar installed power needed: 372 MW Turbines needed: 59		
2029	Homes: 926.433 Total energy need for homes: 4,818 GWh/yr Solar installed power needed: 4,596 MW Turbines needed: 1,031	Homes: 48.512 Total energy need for homes: 182 GWh/yr Solar installed power needed: 164 MW Turbines needed: 19				Homes: 55.771 Total energy need for homes: 228 GWh/yr Solar installed power needed: 215 MW Turbines needed: 37	Homes: 59.225 Total energy need for homes: 202 GWh/yr Solar installed power needed: 152 MW Turbines needed: 16	Homes: 30.724 Total energy need for homes: 199 GWh/yr Solar installed power needed: 171 MW Turbines needed: 19	Homes: 105.759 Total energy need for homes: 530 GWh/yr Solar installed power needed: 452 MW Turbines needed: 76	Homes: 30.107 Total energy need for homes: 112 GWh/yr Solar installed power needed: 86 MW Turbines needed: 11	
2030	Homes: 807.854 Total energy need for homes: 3,829 GWh/yr Solar installed power needed: 3,569 MW Turbines needed: 741	Homes: 43.682 Total energy need for homes: 210 GWh/yr Solar installed power needed: 185 MW Turbines needed: 19	Homes: 137.660 Total energy need for homes: 689 GWh/yr Solar installed power needed: 617 MW Turbines needed: 138	Homes: 79.852 Total energy need for homes: 339 GWh/yr Solar installed power needed: 284 MW Turbines needed: 73	Homes: 22.848 Total energy need for homes: 141 GWh/yr Solar installed power needed: 114 MW Turbines needed: 12	Homes: 48.943 Total energy need for homes: 257 GWh/yr Solar installed power needed: 247 MW Turbines needed: 26	Homes: 25.082 Total energy need for homes: 87 GWh/yr Solar installed power needed: 65 MW Turbines needed: 7		Homes: 16.014 Total energy need for homes: 91 GWh/yr Solar installed power needed: 77 MW Turbines needed: 19	Homes: 162.769 Total energy need for homes: 360 GWh/yr Solar installed power needed: 319 MW Turbines needed: 41	
2031	Homes: 1.133.251 Total energy need for homes: 5,830 GWh/yr Solar installed power needed: 5,506 MW Turbines needed: 1,754	Homes: 57.097 Total energy need for homes: 316 GWh/yr Solar installed power needed: 280 MW Turbines needed: 48	Homes: 11.818 Total energy need for homes: 75 GWh/yr Solar installed power needed: 72 MW Turbines needed: 25	Homes: 50.643 Total energy need for homes: 237 GWh/yr Solar installed power needed: 204 MW Turbines needed: 45	Homes: 10.759 Total energy need for homes: 72 GWh/yr Solar installed power needed: 62 MW Turbines needed: 7	Homes: 73.641 Total energy need for homes: 210 GWh/yr Solar installed power needed: 209 MW Turbines needed: 35	Homes: 220.027 Total energy need for homes: 746 GWh/yr Solar installed power needed: 578 MW Turbines needed: 62	Homes: 25.078 Total energy need for homes: 108 GWh/yr Solar installed power needed: 84 MW Turbines needed: 9		Homes: 34.793 Total energy need for homes: 82 GWh/yr Solar installed power needed: 62 MW Turbines needed: 9	Homes: 71.161 Total energy need for homes: 174 GWh/yr Solar installed power needed: 145 MW Turbines needed: 15
2032	Homes: 1.637.920 Total energy need for homes: 8,522 GWh/yr Solar installed power needed: 8,246 MW Turbines needed: 2,693	Homes: 70.951 Total energy need for homes: 333 GWh/yr Solar installed power needed: 296 MW Turbines needed: 35	Homes: 123.227 Total energy need for homes: 609 GWh/yr Solar installed power needed: 576 MW Turbines needed: 159	Homes: 36.925 Total energy need for homes: 188 GWh/yr Solar installed power needed: 156 MW Turbines needed: 43		Homes: 105.386 Total energy need for homes: 424 GWh/yr Solar installed power needed: 411 MW Turbines needed: 67	Homes: 152.925 Total energy need for homes: 496 GWh/yr Solar installed power needed: 386 MW Turbines needed: 41		Homes: 10.414 Total energy need for homes: 60 GWh/yr Solar installed power needed: 51 MW Turbines needed: 13	Homes: 291.896 Total energy need for homes: 805 GWh/yr Solar installed power needed: 670 MW Turbines needed: 94	
2033	Homes: 1.678.929 Total energy need for homes: 7,213 GWh/yr Solar installed power needed: 6,959 MW Turbines needed: 1,690	Homes: 82.817 Total energy need for homes: 247 GWh/yr Solar installed power needed: 219 MW Turbines needed: 32	Homes: 42.464 Total energy need for homes: 165 GWh/yr Solar installed power needed: 157 MW Turbines needed: 30	Homes: 16.775 Total energy need for homes: 53 GWh/yr Solar installed power needed: 46 MW Turbines needed: 6	Homes: 21.132 Total energy need for homes: 68 GWh/yr Solar installed power needed: 56 MW Turbines needed: 6	Homes: 202.577 Total energy need for homes: 665 GWh/yr Solar installed power needed: 657 MW Turbines needed: 103	Homes: 76.315 Total energy need for homes: 241 GWh/yr Solar installed power needed: 188 MW Turbines needed: 19		Homes: 65.395 Total energy need for homes: 249 GWh/yr Solar installed power needed: 216 MW Turbines needed: 42	Homes: 263.175 Total energy need for homes: 599 GWh/yr Solar installed power needed: 485 MW Turbines needed: 59	Homes: 49.082 Total energy need for homes: 166 GWh/yr Solar installed power needed: 148 MW Turbines needed: 16
2034	Homes: 2.474.712 Total energy need for homes: 12,162 GWh/yr Solar installed power needed: 11,831 MW Turbines needed: 3,123	Homes: 45.833 Total energy need for homes: 176 GWh/yr Solar installed power needed: 151 MW Turbines needed: 23	Homes: 155.982 Total energy need for homes: 624 GWh/yr Solar installed power needed: 584 MW Turbines needed: 113	Homes: 57.867 Total energy need for homes: 209 GWh/yr Solar installed power needed: 178 MW Turbines needed: 38		Homes: 241.379 Total energy need for homes: 833 GWh/yr Solar installed power needed: 815 MW Turbines needed: 129	Homes: 214.366 Total energy need for homes: 692 GWh/yr Solar installed power needed: 537 MW Turbines needed: 55	Homes: 32.597 Total energy need for homes: 179 GWh/yr Solar installed power needed: 153 MW Turbines needed: 17	Homes: 45.753 Total energy need for homes: 144 GWh/yr Solar installed power needed: 128 MW Turbines needed: 23	Homes: 280.587 Total energy need for homes: 798 GWh/yr Solar installed power needed: 670 MW Turbines needed: 91	
2035	Homes: 2.489.097 Total energy need for homes: 11,918 GWh/yr Solar installed power needed: 11,659 MW Turbines needed: 2,973	Homes: 70.553 Total energy need for homes: 317 GWh/yr Solar installed power needed: 276 MW Turbines needed: 38	Homes: 135.676 Total energy need for homes: 566 GWh/yr Solar installed power needed: 519 MW Turbines needed: 88	Homes: 94.687 Total energy need for homes: 457 GWh/yr Solar installed power needed: 387 MW Turbines needed: 106	Homes: 4.179 Total energy need for homes: 29 GWh/yr Solar installed power needed: 24 MW Turbines needed: 3	Homes: 282.956 Total energy need for homes: 991 GWh/yr Solar installed power needed: 973 MW Turbines needed: 145	Homes: 285.372 Total energy need for homes: 791 GWh/yr Solar installed power needed: 620 MW Turbines needed: 67	Homes: 8.677 Total energy need for homes: 49 GWh/yr Solar installed power needed: 42 MW Turbines needed: 5	Homes: 75.856 Total energy need for homes: 284 GWh/yr Solar installed power needed: 249 MW Turbines needed: 46	Homes: 176.847 Total energy need for homes: 452 GWh/yr Solar installed power needed: 381 MW Turbines needed: 52	Homes: 121.496 Total energy need for homes: 269 GWh/yr Solar installed power needed: 232 MW Turbines needed: 22
2036	Homes: 2.651.945 Total energy need for homes: 12,866 GWh/yr Solar installed power needed: 12,528 MW Turbines needed: 3,223	Homes: 68.332 Total energy need for homes: 288 GWh/yr Solar installed power needed: 248 MW Turbines needed: 36	Homes: 211.510 Total energy need for homes: 762 GWh/yr Solar installed power needed: 688 MW Turbines needed: 122	Homes: 47.281 Total energy need for homes: 223 GWh/yr Solar installed power needed: 188 MW Turbines needed: 53	Homes: 6.581 Total energy need for homes: 46 GWh/yr Solar installed power needed: 39 MW Turbines needed: 4	Homes: 240.654 Total energy need for homes: 779 GWh/yr Solar installed power needed: 767 MW Turbines needed: 118	Homes: 168.838 Total energy need for homes: 467 GWh/yr Solar installed power needed: 360 MW Turbines needed: 38	Homes: 30.099 Total energy need for homes: 127 GWh/yr Solar installed power needed: 105 MW Turbines needed: 12	Homes: 81.389 Total energy need for homes: 316 GWh/yr Solar installed power needed: 277 MW Turbines needed: 49	Homes: 269.177 Total energy need for homes: 729 GWh/yr Solar installed power needed: 601 MW Turbines needed: 78	Homes: 49.671 Total energy need for homes: 117 GWh/yr Solar installed power needed: 97 MW Turbines needed: 11
2037	Homes: 2.455.573 Total energy need for homes: 12,703 GWh/yr Solar installed power needed: 12,435 MW Turbines needed: 3,274	Homes: 58.826 Total energy need for homes: 269 GWh/yr Solar installed power needed: 236 MW Turbines needed: 32	Homes: 212.440 Total energy need for homes: 753 GWh/yr Solar installed power needed: 690 MW Turbines needed: 114	Homes: 57.272 Total energy need for homes: 291 GWh/yr Solar installed power needed: 245 MW Turbines needed: 74	Homes: 24.205 Total energy need for homes: 94 GWh/yr Solar installed power needed: 77 MW Turbines needed: 8	Homes: 181.686 Total energy need for homes: 704 GWh/yr Solar installed power needed: 687 MW Turbines needed: 102	Homes: 145.473 Total energy need for homes: 424 GWh/yr Solar installed power needed: 325 MW Turbines needed: 35	Homes: 45.182 Total energy need for homes: 238 GWh/yr Solar installed power needed: 200 MW Turbines needed: 23	Homes: 123.916 Total energy need for homes: 413 GWh/yr Solar installed power needed: 360 MW Turbines needed: 57	Homes: 212.804 Total energy need for homes: 588 GWh/yr Solar installed power needed: 490 MW Turbines needed: 62	Homes: 46.690 Total energy need for homes: 145 GWh/yr Solar installed power needed: 127 MW Turbines needed: 13
2038	Homes: 1.964.082 Total energy need for homes: 10,620 GWh/yr Solar installed power needed: 10,420 MW Turbines needed: 3,005	Homes: 29.415 Total energy need for homes: 121 GWh/yr Solar installed power needed: 106 MW Turbines needed: 14	Homes: 117.319 Total energy need for homes: 585 GWh/yr Solar installed power needed: 548 MW Turbines needed: 109	Homes: 51.935 Total energy need for homes: 289 GWh/yr Solar installed power needed: 245 MW Turbines needed: 57	Homes: 14.904 Total energy need for homes: 82 GWh/yr Solar installed power needed: 68 MW Turbines needed: 7	Homes: 168.975 Total energy need for homes: 700 GWh/yr Solar installed power needed: 676 MW Turbines needed: 100	Homes: 156.666 Total energy need for homes: 377 GWh/yr Solar installed power needed: 285 MW Turbines needed: 30	Homes: 38.748 Total energy need for homes: 196 GWh/yr Solar installed power needed: 165 MW Turbines needed: 19	Homes: 138.789 Total energy need for homes: 500 GWh/yr Solar installed power needed: 436 MW Turbines needed: 81	Homes: 163.652 Total energy need for homes: 484 GWh/yr Solar installed power needed: 410 MW Turbines needed: 52	Homes: 55.900 Total energy need for homes: 118 GWh/yr Solar installed power needed: 104 MW Turbines needed: 11
2039	Homes: 1.692.847 Total energy need for homes: 9,973 GWh/yr Solar installed power needed: 9,804 MW Turbines needed: 3,085	Homes: 61.838 Total energy need for homes: 292 GWh/yr Solar installed power needed: 257 MW Turbines needed: 36	Homes: 87.236 Total energy need for homes: 440 GWh/yr Solar installed power needed: 410 MW Turbines needed: 80	Homes: 31.807 Total energy need for homes: 184 GWh/yr Solar installed power needed: 154 MW Turbines needed: 39	Homes: 14.854 Total energy need for homes: 84 GWh/yr Solar installed power needed: 70 MW Turbines needed: 8	Homes: 123.321 Total energy need for homes: 515 GWh/yr Solar installed power needed: 499 MW Turbines needed: 72	Homes: 88.753 Total energy need for homes: 205 GWh/yr Solar installed power needed: 153 MW Turbines needed: 16	Homes: 28.727 Total energy need for homes: 137 GWh/yr Solar installed power needed: 112 MW Turbines needed: 13	Homes: 93.608 Total energy need for homes: 339 GWh/yr Solar installed power needed: 295 MW Turbines needed: 51	Homes: 138.475 Total energy need for homes: 326 GWh/yr Solar installed power needed: 289 MW Turbines needed: 35	Homes: 67.774 Total energy need for homes: 206 GWh/yr Solar installed power needed: 181 MW Turbines needed: 18
2040	Homes: 1.204.208 Total energy need for homes: 7,194 GWh/yr Solar installed power needed: 7,029 MW Turbines needed: 1,996	Homes: 31.016 Total energy need for homes: 147 GWh/yr Solar installed power needed: 129 MW Turbines needed: 20	Homes: 64.792 Total energy need for homes: 312 GWh/yr Solar installed power needed: 285 MW Turbines needed: 62	Homes: 37.364 Total energy need for homes: 262 GWh/yr Solar installed power needed: 219 MW Turbines needed: 63	Homes: 7.589 Total energy need for homes: 50 GWh/yr Solar installed power needed: 42 MW Turbines needed: 5	Homes: 104.152 Total energy need for homes: 387 GWh/yr Solar installed power needed: 376 MW Turbines needed: 49	Homes: 47.497 Total energy need for homes: 127 GWh/yr Solar installed power needed: 96 MW Turbines needed: 10	Homes: 24.573 Total energy need for homes: 144 GWh/yr Solar installed power needed: 122 MW Turbines needed: 14	Homes: 65.174 Total energy need for homes: 234 GWh/yr Solar installed power needed: 204 MW Turbines needed: 35	Homes: 116.705 Total energy need for homes: 366 GWh/yr Solar installed power needed: 327 MW Turbines needed: 40	Homes: 72.638 Total energy need for homes: 189 GWh/yr Solar installed power needed: 163 MW Turbines needed: 18
2041	Homes: 1.004.282 Total energy need for homes: 6,130 GWh/yr Solar installed power needed: 5,967 MW Turbines needed: 1,944	Homes: 23.386 Total energy need for homes: 125 GWh/yr Solar installed power needed: 109 MW Turbines needed: 15	Homes: 51.212 Total energy need for homes: 260 GWh/yr Solar installed power needed: 239 MW Turbines needed: 51	Homes: 33.938 Total energy need for homes: 240 GWh/yr Solar installed power needed: 200 MW Turbines needed: 56	Homes: 10.317 Total energy need for homes: 62 GWh/yr Solar installed power needed: 51 MW Turbines needed: 6	Homes: 61.462 Total energy need for homes: 269 GWh/yr Solar installed power needed: 260 MW Turbines needed: 39	Homes: 66.502 Total energy need for homes: 132 GWh/yr Solar installed power needed: 99 MW Turbines needed: 11	Homes: 13.156 Total energy need for homes: 74 GWh/yr Solar installed power needed: 62 MW Turbines needed: 7	Homes: 80.340 Total energy need for homes: 257 GWh/yr Solar installed power needed: 226 MW Turbines needed: 42	Homes: 92.005 Total energy need for homes: 258 GWh/yr Solar installed power needed: 231 MW Turbines needed: 28	Homes: 40.842 Total energy need for homes: 123 GWh/yr Solar installed power needed: 107 MW Turbines needed: 11
2042	Homes: 714.321 Total energy need for homes: 4,602 GWh/yr Solar installed power needed: 4,478 MW Turbines needed: 1,431	Homes: 28.178 Total energy need for homes: 156 GWh/yr Solar installed power needed: 136 MW Turbines needed: 18	Homes: 27.028 Total energy need for homes: 128 GWh/yr Solar installed power needed: 118 MW Turbines needed: 20	Homes: 31.827 Total energy need for homes: 238 GWh/yr Solar installed power needed: 199 MW Turbines needed: 53	Homes: 11.880 Total energy need for homes: 69 GWh/yr Solar installed power needed: 57 MW Turbines needed: 6	Homes: 58.770 Total energy need for homes: 216 GWh/yr Solar installed power needed: 209 MW Turbines needed: 30	Homes: 40.450 Total energy need for homes: 84 GWh/yr Solar installed power needed: 63 MW Turbines needed: 7	Homes: 11.311 Total energy need for homes: 59 GWh/yr Solar installed power needed: 50 MW Turbines needed: 6	Homes: 43.121 Total energy need for homes: 160 GWh/yr Solar installed power needed: 138 MW Turbines needed: 24	Homes: 68.907 Total energy need for homes: 197 GWh/yr Solar installed power needed: 170 MW Turbines needed: 20	Homes: 35.141 Total energy need for homes: 132 GWh/yr Solar installed power needed: 119 MW Turbines needed: 13
2043	Homes: 479.989 Total energy need for homes: 3,454 GWh/yr Solar installed power needed: 3,358 MW Turbines needed: 1,180	Homes: 14.031 Total energy need for homes: 80 GWh/yr Solar installed power needed: 70 MW Turbines needed: 12	Homes: 22.685 Total energy need for homes: 117 GWh/yr Solar installed power needed: 108 MW Turbines needed: 21	Homes: 23.646 Total energy need for homes: 172 GWh/yr Solar installed power needed: 144 MW Turbines needed: 37	Homes: 17.623 Total energy need for homes: 110 GWh/yr Solar installed power needed: 92 MW Turbines needed: 10	Homes: 21.949 Total energy need for homes: 100 GWh/yr Solar installed power needed: 96 MW Turbines needed: 14	Homes: 16.612 Total energy need for homes: 54 GWh/yr Solar installed power needed: 41 MW Turbines needed: 4	Homes: 9.739 Total energy need for homes: 54 GWh/yr Solar installed power needed: 46 MW Turbines needed: 5	Homes: 28.460 Total energy need for homes: 96 GWh/yr Solar installed power needed: 83 MW Turbines needed: 14	Homes: 28.370 Total energy need for homes: 86 GWh/yr Solar installed power needed: 79 MW Turbines needed: 10	Homes: 42.482 Total energy need for homes: 161 GWh/yr Solar installed power needed: 141 MW Turbines needed: 15
2044	Homes: 399.521 Total energy need for homes: 2,583 GWh/yr Solar installed power needed: 2,503 MW Turbines needed: 957	Homes: 6.443 Total energy need for homes: 35 GWh/yr Solar installed power needed: 30 MW Turbines needed: 5	Homes: 19.851 Total energy need for homes: 92 GWh/yr Solar installed power needed: 84 MW Turbines needed: 15	Homes: 16.045 Total energy need for homes: 111 GWh/yr Solar installed power needed: 92 MW Turbines needed: 25	Homes: 8.943 Total energy need for homes: 52 GWh/yr Solar installed power needed: 42 MW Turbines needed: 5	Homes: 27.972 Total energy need for homes: 85 GWh/yr Solar installed power needed: 81 MW Turbines needed: 13	Homes: 13.006 Total energy need for homes: 31 GWh/yr Solar installed power needed: 24 MW Turbines needed: 3	Homes: 6.456 Total energy need for homes: 40 GWh/yr Solar installed power needed: 34 MW Turbines needed: 4	Homes: 27.070 Total energy need for homes: 80 GWh/yr Solar installed power needed: 71 MW Turbines needed: 12	Homes: 30.178 Total energy need for homes: 74 GWh/yr Solar installed power needed: 68 MW Turbines needed: 8	Homes: 40.893 Total energy need for homes: 100 GWh/yr Solar installed power needed: 88 MW Turbines needed: 9
2045	Homes: 227.157 Total energy need for homes: 1,608 GWh/yr Solar installed power needed: 1,556 MW Turbines needed: 571	Homes: 6.138 Total energy need for homes: 35 GWh/yr Solar installed power needed: 30 MW Turbines needed: 5	Homes: 16.096 Total energy need for homes: 101 GWh/yr Solar installed power needed: 96 MW Turbines needed: 22	Homes: 10.119 Total energy need for homes: 77 GWh/yr Solar installed power needed: 64 MW Turbines needed: 16	Homes: 3.752 Total energy need for homes: 21 GWh/yr Solar installed power needed: 17 MW Turbines needed: 2	Homes: 11.293 Total energy need for homes: 55 GWh/yr Solar installed power needed: 52 MW Turbines needed: 8	Homes: 7.471 Total energy need for homes: 19 GWh/yr Solar installed power needed: 15 MW Turbines needed: 2	Homes: 3.049 Total energy need for homes: 16 GWh/yr Solar installed power needed: 13 MW Turbines needed: 1	Homes: 22.786 Total energy need for homes: 85 GWh/yr Solar installed power needed: 75 MW Turbines needed: 12	Homes: 7.779 Total energy need for homes: 24 GWh/yr Solar installed power needed: 20 MW Turbines needed: 2	Homes: 20.673 Total energy need for homes: 78 GWh/yr Solar installed power needed: 67 MW Turbines needed: 7
2046	Homes: 135.359 Total energy need for homes: 913 GWh/yr Solar installed power needed: 885 MW Turbines needed: 281	Homes: 2.639 Total energy need for homes: 18 GWh/yr Solar installed power needed: 16 MW Turbines needed: 2	Homes: 4.288 Total energy need for homes: 19 GWh/yr Solar installed power needed: 18 MW Turbines needed: 3	Homes: 10.917 Total energy need for homes: 77 GWh/yr Solar installed power needed: 64 MW Turbines needed: 16	Homes: 2.772 Total energy need for homes: 18 GWh/yr Solar installed power needed: 15 MW Turbines needed: 2	Homes: 7.088 Total energy need for homes: 30 GWh/yr Solar installed power needed: 28 MW Turbines needed: 5	Homes: 7.733 Total energy need for homes: 23 GWh/yr Solar installed power needed: 17 MW Turbines needed: 2	Homes: 1.424 Total energy need for homes: 8 GWh/yr Solar installed power needed: 7 MW Turbines needed: 1	Homes: 9.891 Total energy need for homes: 33 GWh/yr Solar installed power needed: 29 MW Turbines needed: 5	Homes: 11.360 Total energy need for homes: 35 GWh/yr Solar installed power needed: 31 MW Turbines needed: 3	Homes: 7.393 Total energy need for homes: 28 GWh/yr Solar installed power needed: 25 MW Turbines needed: 2
2047	Homes: 269.829 Total energy need for homes: 1,916 GWh/yr Solar installed power needed: 1,864 MW Turbines needed: 732	Homes: 5.042 Total energy need for homes: 29 GWh/yr Solar installed power needed: 25 MW Turbines needed: 4	Homes: 9.696 Total energy need for homes: 54 GWh/yr Solar installed power needed: 51 MW Turbines needed: 9	Homes: 11.482 Total energy need for homes: 78 GWh/yr Solar installed power needed: 65 MW Turbines needed: 17	Homes: 2.524 Total energy need for homes: 16 GWh/yr Solar installed power needed: 13 MW Turbines needed: 1	Homes: 17.418 Total energy need for homes: 62 GWh/yr Solar installed power needed: 59 MW Turbines needed: 10		Homes: 7.381 Total energy need for homes: 40 GWh/yr Solar installed power needed: 33 MW Turbines needed: 4	Homes: 18.971 Total energy need for homes: 52 GWh/yr Solar installed power needed: 46 MW Turbines needed: 8	Homes: 16.946 Total energy need for homes: 56 GWh/yr Solar installed power needed: 52 MW Turbines needed: 6	Homes: 24.012 Total energy need for homes: 74 GWh/yr Solar installed power needed: 65 MW Turbines needed: 7
2048	Homes: 315.926 Total energy need for homes: 2,093 GWh/yr Solar installed power needed: 2,057 MW Turbines needed: 735	Homes: 7.031 Total energy need for homes: 35 GWh/yr Solar installed power needed: 30 MW Turbines needed: 5	Homes: 19.592 Total energy need for homes: 94 GWh/yr Solar installed power needed: 88 MW Turbines needed: 15	Homes: 8.380 Total energy need for homes: 58 GWh/yr Solar installed power needed: 49 MW Turbines needed: 13	Homes: 7.107 Total energy need for homes: 42 GWh/yr Solar installed power needed: 35 MW Turbines needed: 4	Homes: 13.724 Total energy need for homes: 53 GWh/yr Solar installed power needed: 51 MW Turbines needed: 8	Homes: 3.183 Total energy need for homes: 6 GWh/yr Solar installed power needed: 4 MW Turbines needed: 0	Homes: 2.227 Total energy need for homes: 10 GWh/yr Solar installed power needed: 8 MW Turbines needed: 1	Homes: 18.126 Total energy need for homes: 52 GWh/yr Solar installed power needed: 46 MW Turbines needed: 7	Homes: 14.381 Total energy need for homes: 45 GWh/yr Solar installed power needed: 43 MW Turbines needed: 5	Homes: 51.727 Total energy need for homes: 158 GWh/yr Solar installed power needed: 137 MW Turbines needed: 14
2049	Homes: 386.123 Total energy need for homes: 2,466 GWh/yr Solar installed power needed: 2,383 MW Turbines needed: 888	Homes: 8.844 Total energy need for homes: 63 GWh/yr Solar installed power needed: 54 MW Turbines needed: 9	Homes: 21.590 Total energy need for homes: 128 GWh/yr Solar installed power needed: 124 MW Turbines needed: 20	Homes: 17.771 Total energy need for homes: 137 GWh/yr Solar installed power needed: 115 MW Turbines needed: 29	Homes: 5.191 Total energy need for homes: 28 GWh/yr Solar installed power needed: 23 MW Turbines needed: 3	Homes: 22.365 Total energy need for homes: 78 GWh/yr Solar installed power needed: 74 MW Turbines needed: 12	Homes: 7.349 Total energy need for homes: 14 GWh/yr Solar installed power needed: 10 MW Turbines needed: 1	Homes: 1.729 Total energy need for homes: 7 GWh/yr Solar installed power needed: 6 MW Turbines needed: 1	Homes: 20.208 Total energy need for homes: 58 GWh/yr Solar installed power needed: 51 MW Turbines needed: 8	Homes: 14.599 Total energy need for homes: 40 GWh/yr Solar installed power needed: 38 MW Turbines needed: 4	Homes: 76.994 Total energy need for homes: 215 GWh/yr Solar installed power needed: 186 MW Turbines needed: 19
2050	Homes: 287.060 Total energy need for homes: 2,058 GWh/yr Solar installed power needed: 2,007 MW Turbines needed: 806	Homes: 3.318 Total energy need for homes: 23 GWh/yr Solar installed power needed: 19 MW Turbines needed: 3	Homes: 18.033 Total energy need for homes: 117 GWh/yr Solar installed power needed: 112 MW Turbines needed: 17	Homes: 8.327 Total energy need for homes: 62 GWh/yr Solar installed power needed: 52 MW Turbines needed: 11	Homes: 2.132 Total energy need for homes: 13 GWh/yr Solar installed power needed: 11 MW Turbines needed: 1	Homes: 6.917 Total energy need for homes: 20 GWh/yr Solar installed power needed: 19 MW Turbines needed: 3	Homes: 608 Total energy need for homes: 2 GWh/yr Solar installed power needed: 1 MW Turbines needed: 0	Homes: 1.367 Total energy need for homes: 7 GWh/yr Solar installed power needed: 6 MW Turbines needed: 1	Homes: 4.619 Total energy need for homes: 12 GWh/yr Solar installed power needed: 11 MW Turbines needed: 2	Homes: 5.778 Total energy need for homes: 9 GWh/yr Solar installed power needed: 9 MW Turbines needed: 1	Homes: 51.503 Total energy need for homes: 154 GWh/yr Solar installed power needed: 134 MW Turbines needed: 14

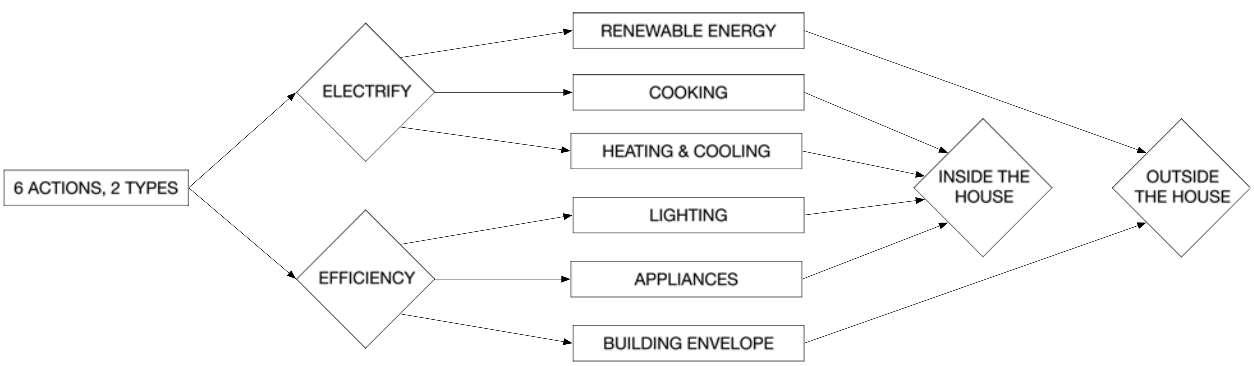
4.7) Acceleration

As it was mentioned on the literature review, there are many contemporary acceleration plans that help to establish which solutions are better on which context, but they all agree that action plans should be local in the sense within a neighbourhood or a group of a few municipalities. As also mentioned, the current problems of acceleration of the renovations of homes is that it requires hundreds of thousands of small projects across the EU which is time and resources that in many places are not available. In this sense, projects like CRREM or ODYSSEE-MURE help to speed up the generation of the assessments. Is also clear that the problems that are still needed to be solved are accelerating the renovation depth, rates, and investment.



Casa in classe energetica, 2022

In terms of depth, it refers to the amount of efficiency that the home improves. It can be measured for example in Italy by the energy categorization a residential property has. We could say that as renovation depth considers around 60% of efficiency improvement, it translates on a home making the necessary works to upgrade its energy classification by 3 categories. As it has been mentioned throughout the research, it is not necessary to upgrade 3 categories all at once, but can be done throughout the years. And also it depends on the specific situation as maybe the home is already aligned with the Italian pathway to net zero. In any case, for achieving depth on improvements towards a decarbonization, there are 6 specific action that can be easily undertaken nowadays.

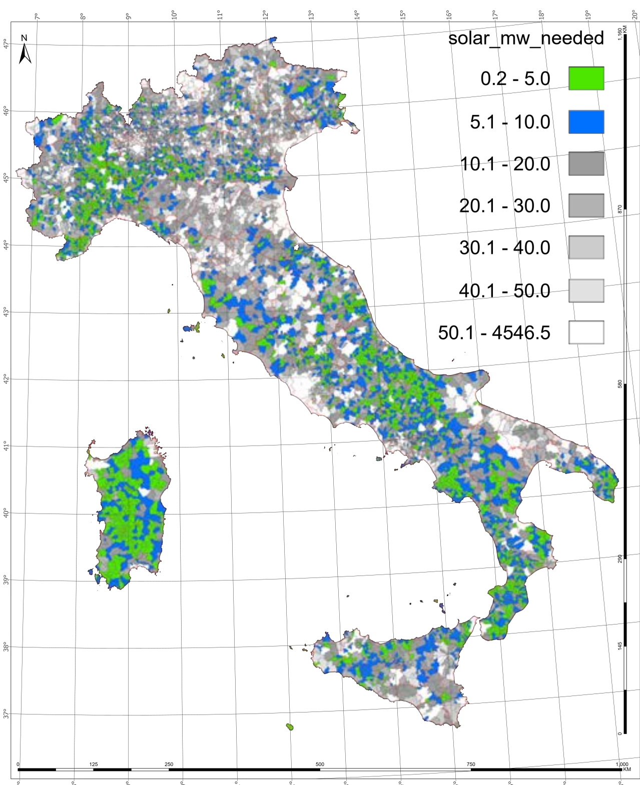


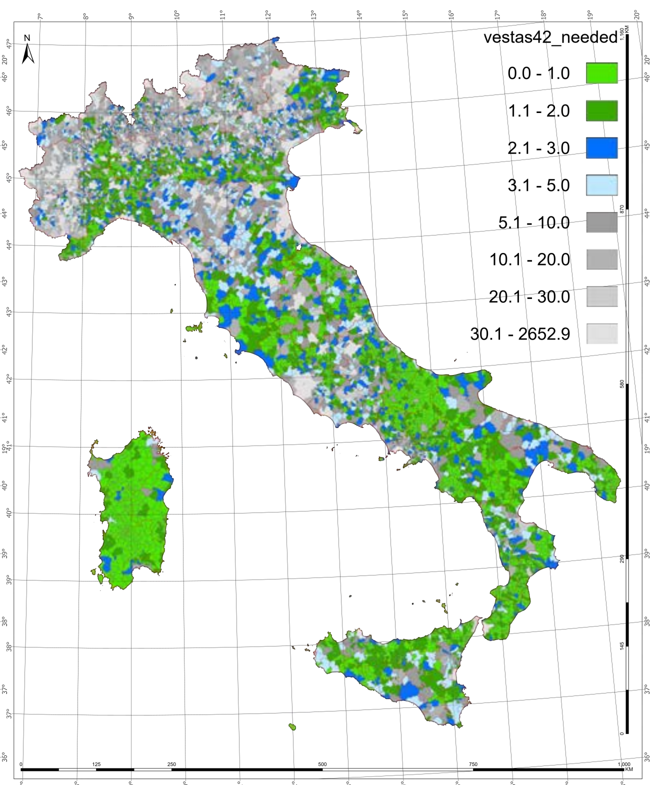
It is reasonable to determine that of these actions, some take place inside the home and others outside. Even if the building envelope can be improved on the inside of the house as well, it is evidently the physical limit with the outside, and renewable energy will always be implemented outside the boundaries of the building envelope. The other 4 actions are more accessible for the resident to improve, but in general terms it is clear that the hard intervention considers renewable energy, heating and cooling and the building envelope. In this sense the first question that needs to be answered is how much renewable energy it is needed and how much can be produced with the alternatives analysed.

Considering the IPCC HDD50 projection of the heating degree days by 2050 and that ODYSSEE-MURE study established that in Italy in 2019 the consumption of energy per degree day per home was 3,83 kWh, a calculation is made in order to estimate how much energy consumption is going to be needed and then how many MW of installed power are therefore needed to cover the demand. As comparison how many wind turbines like the previously analysed would be needed to cover the demand. As equation it is

(IPCC HDD2050 x 3.83 x SUM OF HOMES) / 1000) / (MWh produced by solar or wind)

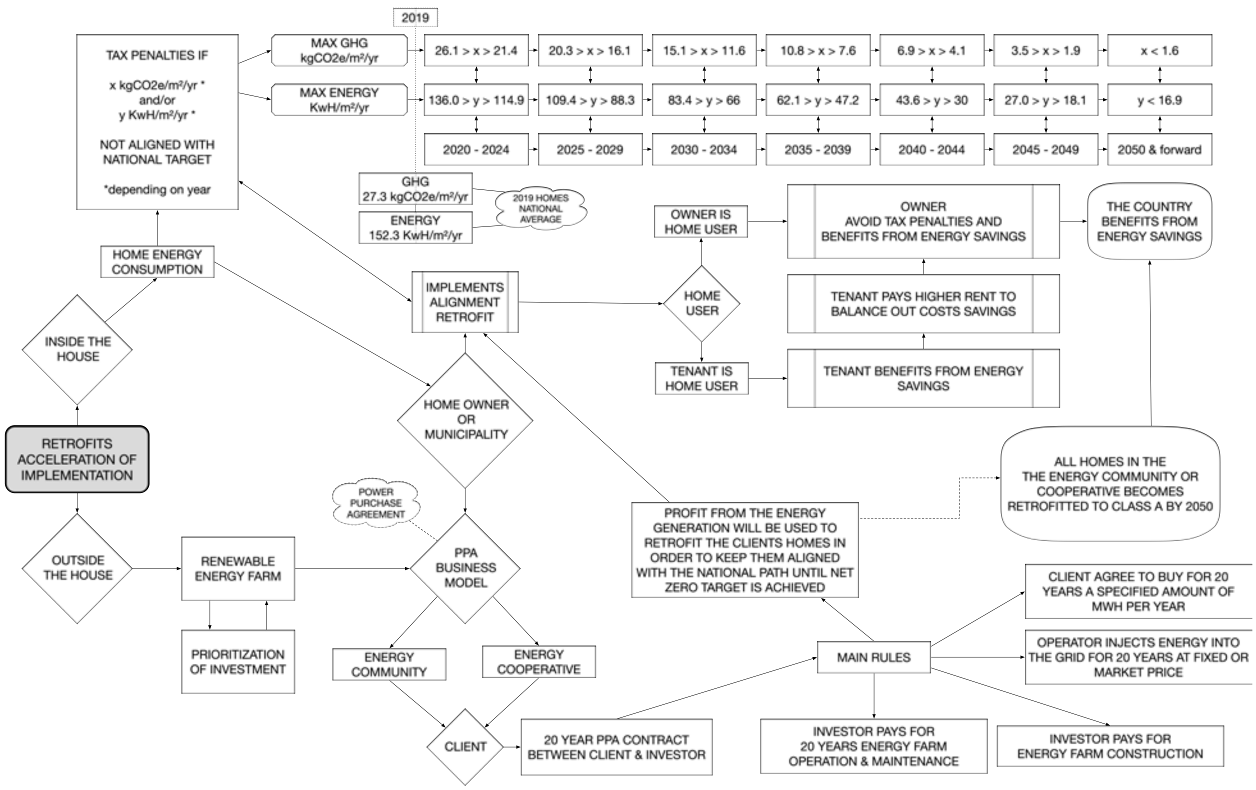
Results are displayed in the case of solar by categories of MW that needs to be installed and in the case of eolic how many IEC3 4.2MW wind turbines could supply the demand. In both cases it can be seen in green and blue colors that there are many municipalities that can cover their needs through small energy farms. Municipalities that are displayed on grey colors are the ones that due to the amount of homes the demand would be too high for a small energy farm and so they should subdivided further through a closer scale analysis, at provincial scale for example, in order to understand the best subdivision.





Results are also presented by municipality on the following table. It shows by region the amount of homes, the energy they need to be renewable by 2050, the solar mw needed to be installed and how many turbines could supply the demand. Through its data it can be understood the pace at which implementation must be performed. Considering that as 2019 residential energy consumption was around 65 TWh, and that the projection calculated determines that by 2050 it will be around 162 TWh, It is more clear that the success of decarbonization resides on the ability to finance the interventions.

To plan the rates in which renovation should happen, this vulnerability assessment provides a suggested order to maintain low risks. Investment on retrofit should be aligned with current new renewable energies investments required, and so being able to use the profits generated by the renewable energy farm to finance the needed investments in retrofit while lowering the national energy grid consumption therefore benefiting the country.



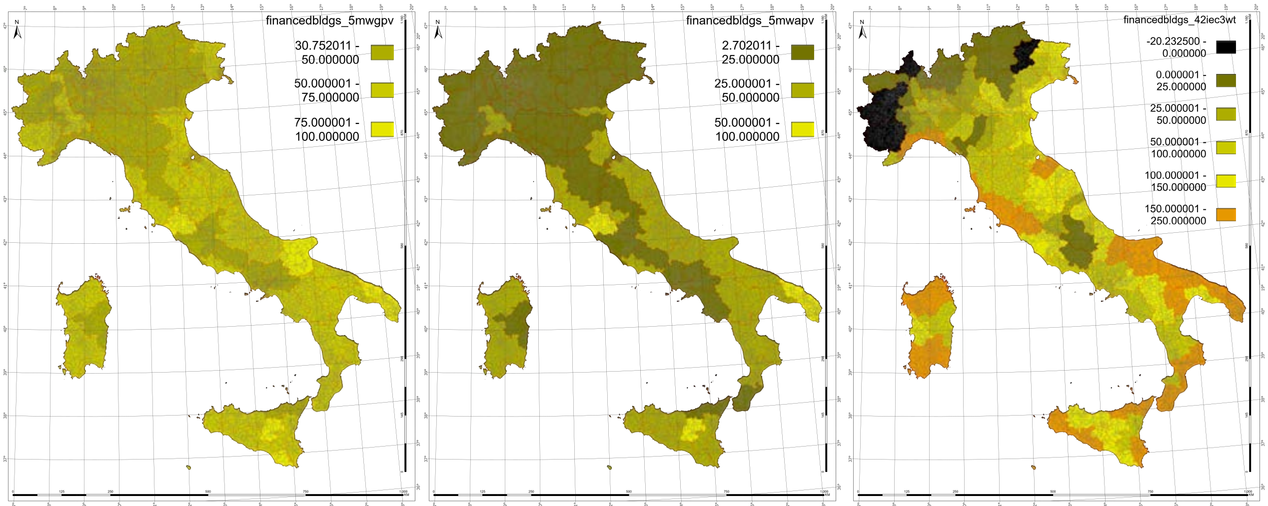
Inside the house refers to the retrofit actions that should be taken in order to improve the efficiency of lighting and appliances, and to electrify cooking, heating and cooling methods used inside the house. Outside the house refers to the building envelope and the provision of renewable energies. It is an opportunity being able to generate electricity with renewables at small scale and provide the necessary funds to implement the needed retrofits on homes. By incentivising power purchase agreements it can be easily financed the investment, as it has been proven during the last decade around the world. The home energy consumption should be in line with the national targets on the road to net-zero by 2050, and so tax benefits or incentives should be considered to be applied if home owners or municipalities don't comply according to their actual annual consumption.

A solution is to establish small renewable energy farms that provide for the needed investment by selling and injecting the produced energy into the energy grid. The main rules that sustain the system are different according to the stakeholder role. Investors pay for the installation of the renewable energy farm and its operation and maintenance for 20 years. The operator injects the energy into the national grid for 20 years at an incentivised, fixed or market price according to the specific plan. For the same 20 years, clients agree to buy a specified amount of MWh per year. By knowing the specific local numbers it can be then established the specific plan and start with the implementation of retrofits. After they are implemented, benefits derive to home users. When is the owner who lives in the home, then he directly gets the benefits of the energy savings. If the home user is a tenant, then he benefits from the energy savings but has to pay higher rent to balance out the costs of savings and so the home owner avoid the costs and the possible penalties for energy consumption. It can be seen with infinite examples that is possible to engage a natural person into investing when offering specific returns within a specific timeframe. In order to do so, in this case it is needed to calculate how much investment can finance how many buildings. Two equations are proposed and analysed:

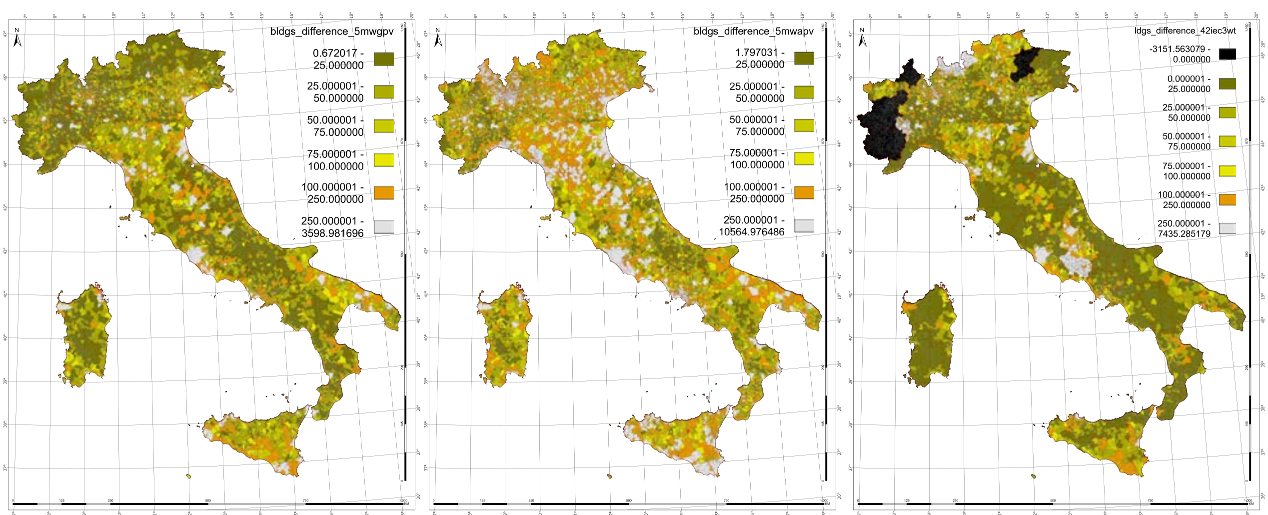
(ROI for each technology) / 100.000 = financed buildings

(Actual Buildings) / (financed buildings) = amount of projects

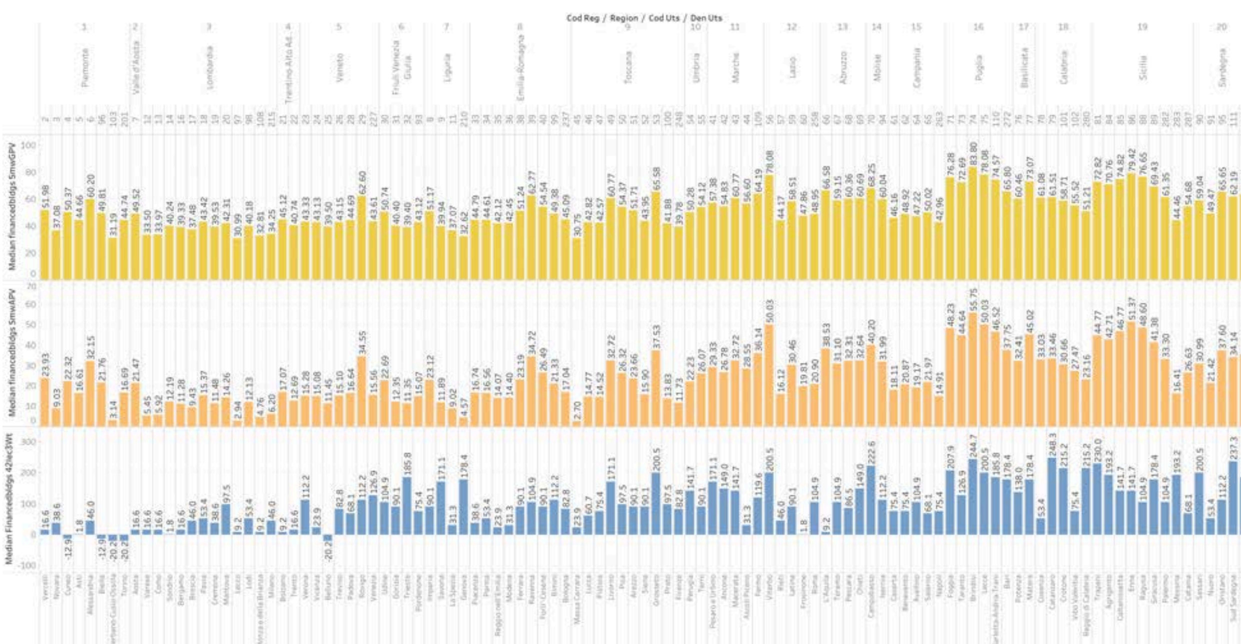
Since the energy potential was made at a provincial scale, the financed buildings are also as a provincial mean value. These are the mean amount of buildings each type of technology can finance, considering a €100.000 per building and the return of investment obtained with an average price for 20 years at €100/MWh, for ground-pv, agro-pv, and wind turbines, in order:



Downscaling to municipality, it is possible to know how many different projects are needed, according to the amount of buildings that each municipality has.



It can be seen that the analysed wind turbines are not profitable in a few provinces, while on the others they always manage to produce the necessary even for retrofitting up to 248 buildings, in the province of Catanzaro, Calabria. This case, the biggest ROI, equals to €24,8M of ROI from a single 4.2MW IEC3 turbine and represents 0,0017% of the total amount needed to be generated and invested into retrofitting in the country. In Italy there are around 14 million residential buildings and with a needed investment of €100.000 per building, it can be established that in Italy the residential retrofit challenge would require an investment of around €1,4 Trillion by 2050. As a reference, achieving the NGFS Net Zero 2050 scenario, it would cost around US$ 275 trillions globally.[70] In this context, the retrofit challenge is actually a problem because of the cost and who pays for it. The most probable scenario is that the US will not spend almost 1 full year of their GDP, or Italy 60% of 1 full year GDP to solve their retrofit problem. As a matter of fact Italy is actually going backwards since residential efficiency has decreased, as it was previously mentioned on the ODYSSEE-MURE energy analysis. It will be up to property owners to solve the problems of their properties, and so this research aims to contribute on guiding them towards a possible solution. Taking the final decision of which technology to use will always depend on the specific location and situation. In Italy for creating a small renewable energy farm (under 5MW) it is needed to ask for regional permits and in some cases also provincial permits which regulate the impact of renewable energy projects. This in addition to the municipality permissions and the national constructions codes that need to also be respected. As a general rule all protected places either for ecological characteristics and cultural heritage are forbidden. It is useful to have the insights this research has produced, as it is now possible to compare scenarios based purely on possible energy production and ROI. It is also good for understanding by province how many buildings are needed to be grouped in order to finance the retrofitting for all.



Indeed the more buildings that a single project can finance, the better, as the cost for each building will be less. As mentioned throughout the results, these mean values by province

[70] McKinsey & Company, 2022

should consider that inside the province there will be municipalities that will perform better and other that will perform worse. As displayed, results allows to visualise the amount of the difference between the technologies analysed.

For example, if we group 30 buildings the scenario would be a total investment of €5.610.000 for 5MW ground-PV, €8.415.000 for 5MW Agro-PV or €3.430.770 for 1x IEC3 4.2MW turbine. Considering that each building will take a loan to finance the investment and that the TAEG (Italian credit rate) is fixed at 6.5% for 20 years, the 240 months paybacks will be by building:

Ground PV=	((5.610.000 x 1,065) / 240) / 30 =	€ 830 per building per month
Agro PV=	((8.415.000 x 1,065) / 240) / 30 =	€1.245 per building per month
Eolic=	((3.430.770 x 1,065) / 240) / 30 =	€ 508 per building per month

If we take the latest national average, therefore 31.036.724 homes divided 14.414.351 buildings equals 2,15 homes per building, we can divide results by it and say that if we group 30 buildings each home should pay around €386 for ground-pv, €579 for agro-pv or €237 for wind turbine projects; in the case we are in a place that we can group 100 buildings and still pay the retrofit for all, then in this case each home would pay monthly €116 for ground-pv, €174 for agro-pv or €71 for wind projects as the ones analysed here.

It is known for any home owner that an improvement in the energy classification improves the value of the property, for sale or rent, in addition to reducing the energy consumption and the monthly energy cost. Finding the perfect technology to use, the perfect amount of buildings to group and the perfect specific location where to build the actual energy farm, are matters of a deeper study that should be carried in a local case, probably within a neighbourhood. Renewable energy technologies improve constantly and so in the future costs might be lower than the mean values considered here. A specific panel or turbine might produce more or less than what is also considered on this research. In no case these results should be considered as the final word on buildings to group or amount to invest, as the case will depend on each local situation. These results should be considered as a reference of what could be achieved with 2022 technology and 2022 prices in Italy. They demonstrate that indeed it makes sense and is possible to finance needed retrofit actions through small energy farms even through a normal home renovation bank credit. They also demonstrate that there are three mature technologies that can be used according to the available budget and of course the estimated amount of buildings that should be expected to be grouped in an energy cooperative or community depending on the specific case.

Considering that on the vulnerability assessment it was also answered the doubt of how many MW each municipality has to install by what year in order for their homes avoid becoming a stranded assets, It can be confidently said that in Italy the retrofit challenge can indeed be solved within the times of acceptable climate risks but it requires the active involvement of property owners in order to finance, as proposed here, their own small renewable energy projects that in turn will finance their properties retrofits while injecting clean renewable energy into the energy matrix therefore decarbonizing the national grid at the same time.

Section 5: Conclusions

5.1) Thesis questions.

5.1.a) Vulnerability

+ What is climate risk in the different parts of the country ?

It is possible to compare municipalities climate risks throughout the country using the methodology proposed on this research which considers three main variables for graduating the risks: climate zone in 2050, which determines the projected energy consumption; municipality current population and amount of buildings; the mean value at risk result for the municipality obtained from the stranding risk analysis. These together allow to obtain a variable that when compared with the results from other municipalities can produce a ranking in descending or ascending order. Also each of these three main variables used, explain different risks by themselves. Higher granularity of the data will produce more precise results but as performed it is definitely possible to identify which municipalities have higher risks than others.

+ According to their risk, what areas should be prioritised ?

The produced ranking by climate risk which include all municipalities should provide a comprehensive list as it also indicates the year by which decarbonization should take place on a specific place. It is believed that decarbonization plans should be considered by province, as some municipalities might not be suitable to install energy farms due to ecological, heritage or other restrictions already in place; some municipalities will perform better than others inside the same province; also because the energy grid infrastructure must be studied at a provincial scale before deciding possible locations for energy farms as it is a key determinant of the project cost. Without a single doubt, the reinforcement of transmission lines and connection infrastructure to the transmission boxes for injecting the energy into the grid is the first element that needs to be studied at a provincial scale. The type of existing poles, if their location is in private or public land, where the transformers and distribution boxes are, what type of cables are already installed, how much load are they currently transmitting, etc is fundamental information as the cost of connecting to the grid can represent the difference between a viable or not project. After that is clear, the next step should be to analyse the different restrictions and regulations in order identify possible real locations and so calculating the real costs and the most realistic production estimation, with the data of the specific system to be implemented. After, organise the works by the vulnerability priority of each municipality residential stock.

5.1.b) Acceleration

+ Renovation rates:

how many homes we need to group together on each action plan ?

Through the acceleration assessment it is possible to grasp an idea about how many buildings, a small, under 5MW renewable energy farm project, could produce on each province and therefore for how many buildings it could finance the needed retrofits in order to be aligned to the net zero paths in terms of energy consumption/efficiency and greenhouse gases emissions. This should be considered as reference, as the actual number by group will depend on knowing the specific location and specific technology used therefore numbers might change but not drastically in any case. For example if this report establishes that a wind turbine of the one analysed is capable to finance 104,9 building's retrofit it means that the turbine has a ROI of €10,49 million and since we are considering an €3,44 million cost, it means that we can rapidly know that if the total cost of the turbine rises to €5 million considering extra expenses, for example to cover a longer distance to the national grid connection, then we immediately know that we could finance the retrofit of 89 buildings at €100.000 each instead of 104, because the ROI now would be €8,93 million. The same applies if the costs of each building retrofit is less than €100.000 each. The value of the acceleration assessment delivered on this research is that it allows to recalculate on the fly the amount of buildings to group after we know the final prices, since we know how much a technology of each characteristic should produce on each location, therefore having more variables available for the pre-design phase of the specific local project.

+ Renovation depth:

It means +60% in efficiency improvement: how do we achieve it ?

As seen on the ODYSSEE-MURE residential energy profile for Italy that was explained earlier on this research we know that around 60% of energy consumption of a home in Italy is for space heating and cooling, and so decarbonizing this item is crucial to achieve the greenhouse gases reductions needed to stay in line with the targets. For this it is needed to electrify the heating and cooling systems used and provide renewable energy for their functioning. Through the financing model proposed it could be possible to achieve the efficiency improvement by retrofitting the buildings envelope and so reduce their heat loss coefficient, improve the energy efficiency and reduce the cost for interior spaces temperature regulation. Another important factor is decarbonizing the electricity source, as it should come from renewable energies and not fossil fuels in order to stay in line with the greenhouse gases reductions national targets and pathway to net-zero. Home owners should also improve the efficiency of their lights, appliances, specially refrigerators, freezers and washing machines, switch to electric cooking and water heating appliances, indeed with a good efficiency, and so achieving a net-zero or a nearly net-zero home. It is important to remember once again that is not necessary to improve everything at once, but just maintain the home within the energy categorization and greenhouse gases emissions in line with the limits by year that the national net-zero pathway determines. Maybe a home currently has an A or A+ categorization and so it is 2050 ready and it would only be needed to make sure there are no greenhouse gases emissions from its functioning, either from inside the house on activities like cooking or heating spaces or the electricity supply. Therefore the energy farm solution applies not only for buildings that need retrofits but also for the ones that need their electricity to be decarbonised. Each home and building is a special case and so it depends on its situation, but it should be evident by now that grouping buildings for an energy farm project would in any case be beneficial. Other improvements could be made on public spaces if a specific building doesn't need the retrofit, or the returns are bigger than the cost of retrofitting, when grouping in smaller numbers for example. It is important to create projects at a local level and plan according to the context and the neighbours objectives and needs. The ranges by province provided on the acceleration report help to quantify the size of the groups and therefore speed up future projects as it provides a complete pre-evaluation.

+ Private investment:

how can we encourage civil society to invest in retrofitting ?

Individually retrofitting a single home or an apartment within a building can be a very expensive task and maybe not even justifiable if the owner is not planning to live there for a decade or possibly more as the reductions in the short term might not even be significant. Indeed each case is different, but it is clear from to the universal market economics and tendencies that the more quantity of the same materials are bought at the same time, the best price a construction of a project gets. When grouping many homes or even buildings not only are the costs of the retrofitting being reduced, but also the whole investment optimised. This makes sense in both cases, in towns or cities where people live agglomerated and in more dispersed sectors where people live in single homes where they will be in any case most probably connected to the same transformer or at least the same distribution substation that connects to the national grid. In Italy there are two different legal entities that can be established by a group of home owners in order to produce their own energy, one is the energy communities, and the other the energy cooperatives. The main difference is that an energy community would install the renewable energy source on their own premises, the energy produced would be 'auto-consumed' inside their own premises, any remnants might be injected into the grid or maybe stored on batteries, and any energy deficit that community will have at a specific time, can still be obtained by the national electricity grid. The energy cooperatives are different because in this case many home owners, independently that if they are physically neighbours or not, finance, in this case, a small renewable energy generation plant that can be located technically anywhere but hopefully nearby so it helps decarbonise their own energy consumption, and every year or as established on the contract they get the dividends of the energy production. In the case of Italy, as of November 2022, energy communities have a very low limit of installed power and therefore the model proposed on this research to finance the buildings retrofits is more in line with the cooperatives than the communities. This indeed could change in the following months or years in Italy and might be different on other countries. Currently the Italian energy communities regulations and incentives are being modified by Italian lawmakers. In any case, producing energy will give the investors earnings in return, either direct or indirect. Direct in the case of the cooperative that pays for the retrofit of the buildings, and indirect in the case of auto consumption of the energy because of the savings that the owner will get by buying less energy from the grid. Indeed the benefits will be different depending on the case of a community or cooperative, specially currently as in the case the community due to the installed power current restrictions in Italy, the dividends won't be too high and probably the produced energy won't even cover half of the whole energy consumption of the homes. As a home owner it does makes sense to be part of a community or cooperative, because the benefits will always be quantifiable and reflected on the property value. By simplifying the process of establishing a cooperative or community and understanding well the potential on each location of the country, they will most probably spread in the future. Another incentive currently not very evident to a home owner, is the stranding risk that the property has due to climate change. It is clear that in the next years the awareness of the impact of climate change on real estate, in terms of energy consumption, will rise and directly affect the market value of the property. This because banks, financing institutions and insurers are increasingly taking in consideration the climate risk of a property before giving a loan, buying an asset or insuring a property. Owners will indeed at some point face the decision of retrofitting by himself, or joining either a community or cooperative that will help pay the retrofit and keep or increase the market value of the specific property. Results provided on this research encourage private investment because increases awareness on the risks and on the opportunities throughout the country.

5.2) Key findings

The proposed methodology explained on this research allowed the clarification of five elements that are fundamental for any decarbonization project, which as any construction or intervention project, will always have a first phase called the evaluation/pre-design phase that will help decide the feasibility, restraints, budgets, etc on the following phase called the design phase. Without entering into the phases of a construction/renovation project which is another subject, the results obtained from this research, independently that indeed are not all the variables required on a pre-design, allow to nurture and speed-up the pre-design phase by providing at national scale, in this case for Italy:

5.2.a) Climate projections to 2050 by municipality

The changes on the temperatures that are projected to happen by mid-century, so in the next 28 years, is without a doubt a fundamental element that needs to be known on any construction project since nowadays the average lifetime of a building is around 50 years. Understanding what will happen in terms of climate during the lifetime of a new construction, or a property that someone might be planning to buy, or an investment into renovating a property that is planned to be used for years to come, or many other cases, even if the owner is not interested in, the banks and insurers most definitely are when establishing the value of a property. This is why we see more and more studies being financed by international entities or governments, etc, whose goals are to predict in the most accurate way, where the temperatures are actually going on a specific location. As of 2022 the international community accepts, as seen at the very beginning of this research, that the most probable scenario is the one called rcp8.5, and so projections on this research are based on that scenario, but it must also acknowledged that no scenario include tipping points or feedback loops, etc, and so it is actually a conservative prediction. Temperatures in 2050 might be higher, but in any case they will be lower. Humanity just doesn't have the capacity yet, on this subject, to create a projection that will be in absolute concordance with reality, and so the best solution at the moment is to compare projections made in the past with actual data and see which projections are the most similar. As explained before, rcp8.5 matches reality since 2019 and so as of 2022 is still the most probable projection but considering it is conservative, and it might be worse. On this research projections applied are from the official IPCC AR6 WG1 CORDEX-EUROPE data from October 2021, and so future projects that use results from this research should consider that climate projections are constantly being updated every few years. In this context a key element found in the case of Italy, is that throughout the Apennines mountains, the climate will be much more colder that the coasts, or said in another way, temperatures will be warmer up to higher altitudes from the sea-level than what it is in the present.

5.2.b) Potential of small, under 5MW, solar or eolic power plants by municipality

From the results obtained it could be determined that in Italy, for supplying the energy demand of their residential stock, considering the demand that they will have by 2050 derived from the climate projections, out of the 7904 municipalities, 2397 (30,3% of the country) need less than 5MW of installed power of solar photovoltaic panels, and 2559 (32,3%) need less than 1 IEC3 4.2MW wind turbine. Therefore it can be confidently said that around 30% of the Italian municipalities can supply energy to their residential stock through a small (under

5MW) renewable energy plant. This also means that around 30% of the municipalities could easily decarbonise their residential energy consumption within the times that their residential stock is affected by the climate risks. It also means that the 30% of the municipalities can improve all their residential stock value at once through one small, under 5MW, renewable energy project. Municipalities that are facing a de-growth of their population and are part of this 30%, have a chance to add value to their homes and attract new residents. Considering results of the potential not in terms of the energy needed, but as a way to finance retrofit actions on buildings, it can be seen that the potential proliferation of small projects is imminent. This because considering the variables explained throughout the research, it can be seen that only 4 municipalities (0,05% of the country) would manage to finance the retrofit of their buildings with only one 5MW solar photovoltaic farm, considering ground-pv, and only 19 municipalities (0,24% of the country) could finance the retrofit of their buildings through one IEC3 4.2MW wind turbine. The other 99,75% of the municipalities would need more than one of these types of projects, at least with the values and technologies analysed on this research. This translates into an evident potential growth of energy communities and cooperatives, as in the country there are around 14 million buildings that need to be retrofitted into energy class A by 2050 and the fact that the residential stock only uses around 23% of the national energy which means there will always be need for the energy produced; a possible solution available today to start financing the retrofit challenge in Italy, is to create more and more energy cooperatives and use their dividends to retrofit the buildings of their members.

5.2.c) Risk of depreciation of homes by province

Results show that by 2050, 41 of the 107 provinces, 38,3% of the country, could have a depreciation of more than 50% of their current market value due to the climate risks, and up to 95% as in the case of the province of Biella, in the Piedmont region. These results obtained using the CRREM tool in the way explained on the methodology, show in general terms that a yearly depreciation above 1,5% can become really problematic if no retrofit actions are planned, as this depreciation percentage considers only climate risks, and should be added the other market depreciation projections that exist in economy. Planning for a retrofit every 10-12 years that will set the property in line with national energy efficiency and greenhouse gases reduction targets can eliminate the stranding risk and even add extra value to the property, what would help mitigate the other economic risks. As seen on the vulnerability assessment, there is still time on almost all municipalities of the country, around 95%, to address this problem. This in any case means that it is recommended to wait before starting to evaluate action plans. It means that considering the timings that burocracy in Italy take to implement a renewable energy project, currently between 4 and 6 years, there is still enough time available to decarbonise safely most of the energy grid, to wait for the these plants to generate the money needed to retrofit the buildings of their cooperatives and to implement those retrofits. It can be said with certainty that the stranding risk of the Italian residential stock, in general terms, it is not a risk that is imminent, but instead is one that needs to be directly addressed within the next decade at least on around 38% of the provinces of the country.

5.2.d) A comparable index of risk that ranks vulnerability by municipality

Thanks to the proposed methodology on this research, a national scale index has been defined. It organises the vulnerability of municipalities in terms of climate projections, resident population and stranding risk, making possible to determine which are the municipalities that need to be decarbonised first than others while also considering that all of them must be decarbonised by 2050 if Italy is going to respect the Paris Agreement commitments that were signed in 2015. Using the index municipalities can be organised by region or province, or climate zone, etc depending on the objective of the categorization. The index has also been divided in 28 categories through a normal step function with equal intervals and each of these categories were related to a specific year. The highest risk is presented as 2023, while the lowest risk as 2050. This derives in that whatever the aggregation of the results, the municipality will keep its year of decarbonization and its specific index value. For example if it is needed to organise vulnerability by region, by provinces, by climate zone inside a region or by municipalities inside a province, etc. since this is a national scale index, the municipality can be compared with all the other municipalities of the country. This also allows to compare the mean value of vulnerability inside a province with total mean value of another province; to compare results by any type of national subdivision; to order by priority provinces, municipalities inside a region or province; etc, and so guiding the order of the execution of action plans. Results helped determine that in the case of Italy, at national level, there are 76 municipalities that stand out with higher risk and should therefore be decarbonised by 2030. The other 7828 can plan for decarbonization within 2031 and 2050. In this sense the urgency can be understood better while being clearly comparable, identified, and understandable so decarbonization plans can organise better their implementation by acting first on those places that are without any doubt more vulnerable than others.

5.2.e) Size of individual acceleration projects to fulfil objectives by municipality

While it is economically obvious that is better to group properties to reduce retrofit costs, what is not instantly clear at all is the size that these groups should be. The procedure proposed consists on first calculating the ROI, return of investment, that a specific technology has on a specific place. Then assuming that the average deep retrofit of a building costs €100.000 according to the European Commission as seen on the literature review. Then the ROI is divided by 100.000 and therefore it is obtained the amount of buildings that a specific technology can finance. By far the most interesting finding for the case of Italy, is how different is the potential of eolic v/s solar. One advantage of solar is that it can be applied exactly according to the specific needs in terms of installed MW of power, differently than a wind turbine that obviously can't be divided. It can be seen from the results that solar panels will produce a positive ROI anywhere on the country, while this specific wind turbine used for the analysis, the most cost effective on-shore wind turbine in the world in 2022 under 5MW, doesn't even repay itself within 20 years in some municipalities. Yet, on the ones that it performs best, its ROI is up to 3 times bigger than solar. The best performing province for solar would finance in its 20 years lifetime, 82 buildings at €100.000 each, while the best performing province for wind in the same time would finance 248 buildings also at €100.000 each. The difference is staggering, and could be the real driver for energy cooperatives to explode in quantity in the near future, because the cost per building can become totally negligible for the home owner and therefore it wouldn't make any sense to not embrace the opportunity. On the other hand solar panels are the technology of choice for energy communities, since they can adapt to the maximum size of installed power that the government currently allows for these type of legal entities, and even if the produced energy might not be as much in some places, they will always help to reduce energy costs. If it is realised that a property can be part of an energy community and the owner at the same time, member of an energy cooperative, it is clear that the full decarbonization of the Italian residential is only on hold because of timings that require to create energy project, but this is something that will be solved in the near future as there is an urgent and mandatory need to install more renewables in Europe.

5.3) Further Discussion

In terms of the methodology proposed on this research, and with the focus on replicability of the analysis on other countries, a question arises about the possible systematisation of the method and steps on a web application, so results could be easily modified live for example to change the cost of installation of a technology or operation and maintenance; granulate the costs of retrofit with real data instead using the average €100.000 value; and easily modify any variables that are needed for the analysis. Through open-source libraries like Python or Leaflet, a web application could be developed in order to make a tool available on the internet, and so any home owner or entrepreneur could analyse if a certain technology makes economic sense on a certain location.

In terms of action plans, since this is a national scale analysis, indeed each region, province and municipality that wish to obtain data like the one obtained on this research, should obtain the more possible granulated data for its context. In this sense it remains open the question on why it is not easily available the data of energy consumption at least by municipality and therefore a valuable contribution of the future development of action plans is to find the way to provide that information and statistics as open access, such as ODYSSEE-MURE does for the national scale.

Section 6: Index of Tables, Images, Graphs and Maps

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11	Image	Figure 1: Stranding diagram	CRREM, 2020, p. 5
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Section 7: Bibliography

Short Reference	Full Reference	On this research:
AFD Group, 2018	AFD Group (2018) *Towards a World in Common. AFD Group 2018-2022 Strategy.*	Text on page 33
ARUP and Ellen McArthur Foundation, 2018	ARUP, Ellen Macarthur Foundation (2018) *From principles to practices: First steps towards a circular built environment.*	Text on page 34
Climate Action Tracker, 2022	Climate Action Tracker (2022) *Decarbonising buildings. Achieving zero carbon heating and cooling. March 2022.*	Text on page 32 and 36; Graph page 76; Image page 32
CRREM, 2020	CRREM (2020) *CRREM Risk Assessment Reference Guide.*	Image page 11
CRREM, 2021	CREEM (2021) *Global Pathways, summary of pathways v.1.093-19.07.2021: Italy multi-family residential buildings, and ODYSSEE-MURE database, Italian households statistics,* Available at https://www.crrem.org/pathways/ (Accessed: 4th December 2022)	Graph page 71; Image page 76
CREEM and UNEP FI, 2022	CREEM, UNEP FI (2022) *Managing transition risk in real estate: Aligning to the Paris Climate Accord. March 2022.*	Text on page 36, 37 and 42
Decreto del Presidente della Repubblica, 2022	Decreto del Presidente della Repubblica (2022) *DPR 412/1993. Allegato A. Ultimo Aggiornamento all'atto pubblicato il 28/04/2022.* Available at https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:legge:1993;412 (Accessed: 4th December 2022)	Text on page 39; Map page 50, 71; Graph page 50, 51, 52
ENEA, 2010	ENEA (2010) *Ricerca di Sistema Elettrico: Edifici tipo, indici di benchmark di consumo per tipologie di edificio, ad uso scolastico (medie superiori e istituti tecnici) applicabilità di tecnologie innovative nei diversi climi italiani; A.P. Corgnati, E. Fabrizio, L. Rollino; Report RSE/2010/190; 2010.*	Text on page 34
Energy Transitions Commission, 2016	Energy Transitions Commission (2016) *Who we are.* Available at https://www.energy-transitions.org/who/ (Accessed: 4th December 2022).	Text on page 29
Energy Transitions Commission, 2021a	Energy Transitions Commission (2021a) *Keeping 1.5ºC Alive. September 2021.*	Text on page 30
Energy Transitions Commission, 2021b	Energy Transitions Commission (2021b) *Assessing the commitments from COP26.* Available at https://www.energy-transitions.org/assessing-the-commitments-from-cop26/ (Accessed: 4th December 2022).	Text on page 30

Short Reference	Full Reference	On this research:
Energy Transitions Commission, 2022	Energy Transitions Commission (2022) *Mind the Gap: How Carbon Dioxide Removals must Complement Deep Decarbonisation to Keep 1.5ºC Alive. March 2022.*	Text on page 30
European Commission, 2020	European Commission (2020) *COM(2020) 662 final. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A renovation wave for Europe - greening our buildings, creating jobs, improving life. (SWD(2020) 550 final).*	Text on page 27, 35 and 37
Fraunhofer ISE, 2020	Fraunhofer ISE (2020) *Agrivoltaics: opportunities for agriculture and the energy transition, A guideline for Germany. Aug. 2020.*	Text on page 65; Table page 65
Gabrielli et al, 2020	Laura Gabrielli, IUAV University of Venice, London Industry Seminar CRREM-ERES (2020) *1st Panel: Climate change impact on real estate, uncertainty and solutions. Stranding Risk. Climate change, stranded assets, stranding risk. September 2020.*	Text on page 36; Image page 11
Global Building Performance Network, 2017	Global Building Performance Network (2017) *Common Carbon Metric 2.0: CCM2.0, Joint UN Environment - UNFCCC Workshop in mitigation in the building sector; Bonn, Germany August 1 2017.*	Text on page 34
Global Solar Atlas 2.7, 2021	Global Solar Atlas 2.7 (2022) *A free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information:* https://globalsolaratlas.info (Accessed: 4th December 2022)	Map page 63
Global Wind Atlas 3.1, 2021	Global Wind Atlas 3.1 (2021) *A free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information:* https://globalwindatlas.info (Accessed: 4th December 2022)	Text on page 44; Map page 63
Green Energy Community et al, 2020	Green Energy Community, Climate-KIC, Agenzia per l'energia e lo sviluppo sostenibile, ENEA, Università di Bologna (2020) *Le comunità energetiche in Italia. Una guida per orientare i cittadini nel nuovo mercato dell'energia.*	Text on page 36
Green Finance Institute, 2021	Green Finance Institute (2021) *Unlocking the Trillions. Public-private innovation to deliver the EU's Renovation Wave ambition. 22nd Nov. 2021.*	Text on page 27

Short Reference	Full Reference	On this research:
GSE, 2022a	GSE (2022a) *Rapporto Statistico 2020. Energia da fonti rinnovabili in Italia. Marzo 2022.*	Text on page 37; Image 37
GSE, 2022b	GSE (2022b) *Solare fotovoltaico 2021. Allegato tabelle provinciali.*	Text on page 44 and 66
GSE, 2022c	GSE (2022c) *Gruppi di autoconsumatori di energia rinnovabile che agiscono collettivamente e comunità di energia rinnovabile. Regole tecniche per l'accesso al servizio di valorizzazione e incentivazione dell'energia elettrica condivisa. April 2022.*	Text on page 37
Immaginacasa.it, 2021	Immaginacasa.it (2021) *Classe energetica.* Available at https://immaginacasa.it/2021/05/bonus-mobili-2021-requisiti-importi-e-tipologie-di-spese-ammesse/ (Accessed: 4th December 2022)	Image page 10, 76
IPCC AR5 WG1, 2013	IPCC AR5 WG1 (2013) *Chapter 12, 2: Long-term Climate Change: Projections, Commitments and Irreversibility.* Available at https://www.ipcc.ch/report/ar5/wg1/long-term-climate-change-projections-commitments-and-irreversibility/ (Accessed: 4th December 2022)	Graph page 8
IPCC AR5 WG3, 2014	IPCC AR5 WG3 (2014) *AR5 Scenario Database,* Available at https://tntcat.iiasa.ac.at/AR5DB/ (Accessed: 4th December 2022)	Graph page 8
IPCC AR6 WG1, 2021a	IPCC AR6 WG1 (2021a) *Interactive Atlas. October 2021.* Available at https://interactive-atlas.ipcc.ch/ (Accessed: 4th December 2022).	Text on page 39
IPCC AR6 WG1, 2021b	IPCC AR6 WG1 (2021b) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, mid-term temperature change, Annual.*	Text on page 46 and 47; Graph page 7; Table page 7; Map page 46
IPCC AR6 WG1, 2021c	IPCC AR6 WG1 (2021c) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, heating degree days, Annual.*	Table page 49; Graph page 50, 51, 52; Map page 50, 71
IPCC AR6 WG1, 2021d	IPCC AR6 WG1 (2021d) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Minimum temperature, Annual.*	Image page 6
IPCC AR6 WG1, 2021e	IPCC AR6 WG1 (2021e) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Maximum temperature, Annual.*	Image page 6

Short Reference	Full Reference	On this research:
IPCC AR6 WG1, 2021f	IPCC AR6 WG1 (2021f) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Mean temperature, Annual.*	Image page 6
IPCC AR6 WG1, 2021g	IPCC AR6 WG1 (2021g) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Minimum of minimum temperature, Annual.*	Image page 6
IPCC AR6 WG1, 2021h	IPCC AR6 WG1 (2021h) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Maximum of maximum temperature, Annual.*	Image page 6
IPCC AR6 WG1, 2021i	IPCC AR6 WG1 (2021i) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Days with temperature above 35ºC, Annual.*	Image page 6
IPCC AR6 WG1, 2021j	IPCC AR6 WG1 (2021j) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Standarized precipitation index, Annual.*	Image page 6
IPCC AR6 WG1, 2021k	IPCC AR6 WG1 (2021k) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Total precipitation, Annual.*	Image page 6
IPCC AR6 WG1, 2021l	IPCC AR6 WG1 (2021l) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Consecutive dry days, Annual.*	Image page 6
IPCC AR6 WG1, 2021m	IPCC AR6 WG1 (2021m) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Frost days, Annual.*	Image page 6
IPCC AR6 WG1, 2021n	IPCC AR6 WG1 (2021n) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Cooling degree days, Annual.*	Image page 6
IPCC AR6 WG1, 2021o	IPCC AR6 WG1 (2021o) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Heating degree days change, Annual.*	Image page 6; Graph page 47
IPCC AR6 WG1, 2021p	IPCC AR6 WG1 (2021p) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, Midterm (2040-2060), Cooling degree days, Annual.*	Image page 6; Graph page 47

Short Reference	Full Reference	On this research:
IPCC AR6 WG1, 2021q	IPCC AR6 WG1 (2021q) *Interactive Atlas. October 2021. Advanced. Settings: Cordex EU, RCP8.5, 1995-2014 baseline, long-term temperature change, Annual.*	Graph & Table page 7
IPCC AR6 WG2, 2022a	IPCC AR6 WG2 (2022a) *Climate change 2022: Impacts, adaptation and vulnerability. 28 Feb.2022.*	Text on page 13
IPCC AR6 WG2, 2022b	IPCC AR6 WG2 (2022b) *Climate change 2022: Impacts, adaptation and vulnerability. Summary for policymakers. 28 Feb.2022.*	Text on page 13 to 23
IPCC, 2018	IPCC (2018) *Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.*	Text on page 30
ISTAT, 2011	ISTAT (2011) *Basi territoriali e variabili censuarie,* Available at https://www.istat.it/it/archivio/104317 (Accessed: 4th December 2022)	Table page 49; Graph page 52, 53, 54, 55; Map page 53
ISTAT, 2022a	ISTAT (2022a) *Confini delle unità amministrative a fini statistici al 1° gennaio 2022, Versione non generalizzata.* Available at https://www.istat.it/it/archivio/222527 (Accessed: 4th December 2022)	Table page 49; Graph page 52, 53, 54, 55; Map page 53, 71
ISTAT, 2022b	ISTAT (2022b) *Popolazione residente al 1° gennaio : Tutti i comuni.* Available at http://dati.istat.it/Index.aspx?QueryId=19101 (Accessed: 4th December 2022)	Table page 49; Graph page 52, 54, 55; Map page 71
Lia, Pizerb and Wu, 2018	Yating Lia, William A. Pizerb and Libo Wu (2018) Climate change and residential electricity consumption in the Yangtze River Delta, China. Available at https://www.pnas.org/doi/pdf/10.1073/pnas.1804667115 (Accessed: 4th December 2022)	Graph page 9
McKinsey & Company, 2022	McKinsey & Company (2022) *Report. The net-zero transition. What it would cost, what it could bring. Jan. 2022*	Text on page 80
Ministero della Transizione Ecologica, 2022	Ministero della Transizione Ecologica (2022) *Linee Guida in materia di Impianti Agrivoltaici. Luglio 2022.*	Text on page 65
Ministero dello Sviluppo Economico, 2019	Ministero dello Sviluppo Economico (2019) *Decreto 4 Luglio 2019. Incentivazione dell'energia elettrica prodotta dagli impianti eolici on shore, solari fotovoltaici, idroelettrici e a gas residuati dei processi di depurazione.*	Text on page 37

Short Reference	Full Reference	On this research:
Mission Possible Partnership, 2021	Mission Possible Partnership (2021) *Action Sectors.* Available at https://missionpossiblepartnership.org/action-sectors/ (Accessed: 4th December 2022).	Text on page 30
Morgan Stanley Institute for Sustainable Investment, 2020	Morgan Stanley Institute for Sustainable Investment (2020) *Climate transition in a portfolio context: what matters and what to measure. July 2020.*	Text on page 35
NASDAQ, 2022	NASDAQ (2022) *Offshore wind in the U.K. is 9 times cheaper than fossil fuels. 26th Aug. 2022.* Available at https://www.nasdaq.com/articles/offshore-wind-in-the-u.k.-is-9-times-cheaper-than-fossil-fuels (Accessed: 4th December 2022)	Text on page 62
New Economics Foundation, 2020	New Economics Foundation (2020) *Homes fit for the future: the retrofit challenge, how will we finance the decarbonisation of homes in Wales to support our net zero ambitions. Executive Summary.*	Text on page 35
ODYSSEE-MURE, 2021a	ODYSSEE-MURE (2021a) *ODYSSEE Database.* Available at https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html (Accessed: 4th December 2022)	Table page 60; Graph page 48, 49
ODYSSE-MURE, 2021b	ODYSSE-MURE (2021b) *Italy. Energy profile, March 2021*	Graph page 56, 61
ODYSSE-MURE, 2021c	ODYSSE-MURE (2021c) *Sectorial energy profile - Households. November 2021*	Graph page 56, 57, 58, 59, 60, 61
Qualenergia.it, 2022a	Qualenergia.it (2022a) *PUN media mensile ultimo due anni.* Available at https://cdn.qualenergia.it/wp-content/uploads/2022/10/pun-media-mensile.jpg (Accessed: 4th December 2022)	Graph page 67
Qualenergia.it, 2022b	Qualenergia.it (2022a) *PUN media annuale 2005-2021.* Available at https://www.qualenergia.it/wp-content/uploads/2022/10/PUN-media-annuale-2005-2021.jpg (Accessed: 4th December 2022)	Graph page 67
Schwalm, Glendon and Duffy, 2020	Christopher R. Schwalm, Spencer Glendon and Philip B. Duffy (2020) *RCP8.5 tracks cumulative CO2 emissions*. Available at https://doi.org/10.1073/pnas.2007117117 (Accessed: 4th December 2022)	Graph page 7
Suri et al, 2007	Suri M., Huld T.A., Dunlop E.D., Ossenbrink H.A. (2007) *Potential of solar electricity generation in the European Union member states and candidate countries.*	Text on page 66
U.K. Government Department for Business, Energy and Industrial Strategy, 2019	U.K. Government Department for Business, Energy and Industrial Strategy (2019) *Accelerating The Low Carbon Transition: the case for stronger, more targeted and coordinated international action.*	Text on page 35

Short Reference	Full Reference	On this research:
UNEP GlobalABC, 2015	UNEP GlobalABC (2015) *History, timeline.* Available at https://globalabc.org/about/history-timeline (Accessed: 4th December 2022).	Text on page 25
UNEP GlobalABC, 2019	UNEP GlobalABC (2019) *A guide for incorporating buildings actions in NDCS. Incorporating fundable buildings sector Green House Gas (GHG) emission mitigation actions in Nationally Determined Contributions (NDCs).*	Text on page 33
UNEP GlobalABC, 2020	UNEP GlobalABC (2020) *GlobalABC Roadmap for Buildings and Construction 2020-2050. Towards a zero-emission, efficient and resilient buildings and construction sector.*	Text on page 31
UNEP GlobalABC, 2021a	UNEP GlobalABC (2021a) *Buildings and Climate Change Adaptation*.	Text on page 26
UNEP GlobalABC, 2021b	UNEP GlobalABC (2021b) *2021 Global status report for buildings and construction. Towards a zero-emissions, efficient and resilient buildings and construction sector.*	Text on page 33
UNEP GlobalABC, 2022a	UNEP GlobalABC (2022a) *GlobalABC documents.* Available at https://globalabc.org/globalabc-documents (Accessed: 4th December 2022).	Text on page 25
UNEP GlobalABC, 2022b	UNEP GlobalABC (2022b) *Adaptation of the building sector to climate change.*	Text on page 26
UNFCCC COP21, 2015	UNFCCC COP21 (2015) *The Paris Agreement*. Available at https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/ (Accessed: 4th December 2022)	Text on page 24
UNFCCC COP22, 2016	UNFCCC COP22 (2016) *Conference of the Parties 22, Marrakech.*	Text on page 24
UNFCCC COP26, 2021a	UNFCCC COP26 (2021) *Conference of the Parties 26, Glasgow.*	Text on page 24
UNFCCC COP26 2021b	UNFCCC (2021b) *UN Climate change conference UK 2021.* Available at https://unfccc-cop26.streamworld.de/ (Accessed: 4th December 2022).	Text on page 25
UNFCCC, 2019	UNFCCC (2019) *Climate Action Pathways.* Available at https://unfccc.int/climate-action/marrakech-partnership/reporting-and-tracking/climate_action_pathways (Accessed: 4th December 2022).	Text on page 24
UNFCCC, 2021	UNFCCC (2021) *Human Settlements - Climate Action Pathway. Vision and Summary*.	Text on page 23, 24, 27 and 31
UNSD, 2017	UNSD (2017) *Principles and recommendations for population and housing censuses. Revision 3.*	Text on page 40

Short Reference	Full Reference	On this research:
WBCSD, 1995	WBCSD (1995) *Our History.* Available at https://www.wbcsd.org/Overview/Our-history (Accessed: 4th December 2022).	Text on page 27
WBCSD, 2020	WBCSD (2020) *The building system carbon framework. A common language for the building and construction value chain.*	Text on page 31
WBCSD, 2021	WBCSD (2021) *Vision 2050: Time to transform. March 2021.*	Text on page 27, 28, 29 and 42