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Building energy renovation for decarbonisation and Covid-19 recovery

A snapshot at regional level

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Foreword by Mariya Gabriel

EUROPEAN COMMISSIONER FOR INNOVATION, RESEARCH, CULTURE, EDUCATION AND YOUTH

On 14 October 2020, the European Commission adopted the Renovation Wave Strategy. This strategy is a fundamental pillar of the implementation of the EU Green Deal, aiming for carbon neutrality by 2050, while supporting the post COVID-19 EU recovery.

I am very pleased that JRC experts have supported the process of developing this European initiative. This present report has great potential in helping the implementation of the renovation wave and supporting action on the ground.

It is the work of a multidisciplinary team of JRC experts, which has studied, at an unprecedented detailed regional level, the existing building stock across the whole of the EU. Taking into account the age of buildings, climatic conditions, structural barriers and key economic indicators, they have identified the most critical regions in terms of renovation needs. Along with estimations of the energy saving potentials, the wider benefits associated with an extensive renovation of residential buildings are presented. The results obtained confirm the strategic need to invest in this sector and lay the foundation for increasing the target of annual renovation rate.

An increased renovation rate, from the current average of 1% to well above 2% within 10 years and maintained thereafter, will result in almost 80% of existing homes being renovated by 2050. This would allow for a 10% reduction of the current total EU primary energy consumption and increase the number of jobs in the construction sector by approximately 20%.

I am confident that this thorough analysis will provide valuable guidance for policy makers in defining their renovation strategies and transforming the built environment at European, national and regional level to a more sustainable and resilient one.

Abstract

Our society and economy are changing as our lifestyles shift in a world recovering from Covid-19. While the governments are working to face this challenge, new local and regional instances stand out. A sustainable recovery throughout Europe calls for a reduction of the existing gaps between regions.

Energy efficiency qualifies as one of the sectors with a greater potential for the double dividend hypothesis, thus supporting economic recovery and decarbonisation simultaneously. Although recent years have witnessed the introduction of various regulatory mechanisms and incentives for efficiency, the energy saving potential of the European building stock is still very high, especially in the residential sector. To activate it, a thirty-year planning and short-term shock measures are required to unlock the efficiency process.

This report provides a snapshot of the European building stock at local level, and identifies the most critical regions, taking into account buildings age, climatic conditions, some structural barriers and key economic indicators. Based on this information, we calculated the energy saving potential of extensive renovation of residential buildings, as well as the associated investment needs and the impact on employment. These indications and datasets can guide decision-makers in the definition of fine-tuned programmes for the refurbishment of existing buildings at European and national level.

Acknowledgements

We are grateful for the useful and constructive comments we received from our reviewers, in particular through the iterative process with the European Commission's Directorate-General for Energy (DG ENER).

Authors

Paolo Zangheri conceived and designed the analysis and wrote this summary report.

Roberto Armani supported the calculation of energy saving potential and contributed for drafting Chapter 3.

Georgia Kakoulaki generated all maps included in the report and contributed for drafting Chapter 2.

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Francesco Pignatelli contributed for drafting Chapter 4.

Claudia Baranzelli contributed for drafting Chapter 4.

Executive summary

The renovation of existing buildings would make a relevant contribution to the improvement of many key aspects of our society and everyday life. Currently, the significantly low energy renovation rates (approximately 1%) across the EU are insufficient to ensure the necessary energy savings, which will need to at least double in the coming years to achieve a climate-neutral European Union by 2050. Boosting the energy performance of buildings will improve the living conditions of citizens and support a wide array of economic sectors. Given the interdependence of EU economies, narrowing the gap between certain regions is a necessary condition to ensure a harmonious, balanced and sustainable growth throughout Europe.

Policy context

Substantial progresses have been made in recent years under the framework of the Energy Performance of Buildings Directive (EPBD) and Energy Efficiency Directive (EED). Nowadays, new buildings tend to operate with less than half of the energy consumed by buildings built 20 years ago. However, because approximately 80% of today's buildings will still be in use in 2050 and 75% of this stock is energy inefficient, the European Green Deal (EGD) foresees to implement the 'Renovation Wave' initiative in this sector, as set out in the 2020 Commission Work Programme. The aim of the EGD is to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy, decoupling economic growth from resource use.

Key conclusions

The analysis of key aspects that affect the energy consumption of residential buildings reveals that critical conditions exist in many European regions, from south to north and from east to west. Looking at the average age of existing buildings, the most critical regions (i.e. with lower average age) are those in north-eastern Germany, South of Belgium, central France and north-western Italy. The share of occupied buildings built before 1990 is higher in the north-east regions (i.e. in Sweden, Estonia, Latvia, Lithuania, Hungary, Romania, and Bulgaria), while the share of historical buildings, built before 1920, is greater in central Europe (i.e. in Belgium, France and Germany). The higher percentages of total non-owner occupied dwellings and rented multi-family buildings concentrate in the urban areas of north-central Europe (such as Stockholm, Berlin, Hamburg, Prague and Wien).

The economy has also been experiencing difficulties in recent years, which are not expected to subside in the near future because of the Covid-19 pandemic. By analysing the period 2018-2021, the lower values of the average GDP per inhabitant are observed in the rural regions of southern and eastern Europe, and the regions of north Italy are those with a greater negative variation of the GDP per inhabitant. The average unemployment rate is expected to be higher (over 20%) in the southern regions of Spain and Italy, and in Greece. The average net disposable income of households (per inhabitant) is very low in all southern and eastern regions. Overall, the most critical regions are located in south Spain, south Italy, Greece and Bulgaria.

The renovation of the residential building stock represents a strategic choice for the recovery of regional economies and a necessity to build a zero-carbon society. It is estimated that performing deep renovations (to NZEB and/or cost-optimal levels) would result in a total (primary) energy saving potential of 2251 TWh (57% of current consumptions). For each European region we quantify the saving potential of renovation, as well as its investment needs and impact on occupations. Observing how the ratio between energy benefit and economic expenditure (as a kind of efficiency) changes among European regions, the highest values were detected in eastern Europe, specifically in Poland, the Czech Republic and Romania.

To exploit this potential, a deeper renovation rate is necessary and if it is linerly increased to 3% within 10 years and mainted thereafter, 79% of existing homes will be renovated by 2050. This would allow to achieve 66% of the technical potential, thus reducing by 1517 TWh the EU primary consumptions (10% of current value). The associated impact on employment would be approximately 55 millions of Full-Time Equivalent job places, with an annual average that represents the 20% of current workforce in the construction sector.

Quick guide

Chapter 1 introduces and frames the study with replies to some key questions. Chapter 2 includes a collection of maps describing the regional residential building stocks. Chapter 3 discusses the energy saving potential associated to existing buildings at NUTS2 level. Chapter 4 discusses further options to generate data at local level. The last chapter draws general conclusions.

1 Introduction

Why is the improvement energy efficiency in buildings a win-to-win option?

The renovation of existing buildings is not the definite cure-all, but it would relevantly contribute to the improvement of many aspects, which play a central role in our society. The environment (i.e. climate change, local pollution and use of resources), economy (i.e. sustainable growth, industry competiveness, job places), energy infrastructure (i.e. energy security and dependency), people wellbeing (i.e. energy poverty, health and living conditions) are the main ones.

The Paris Agreement has set out a global framework to avoid dangerous climate change, by limiting global warming to well below 2°C. The EU building stock is the largest single energy consumer in Europe with 40% of energy consumption and 36% of EU GHG emissions. Because of this specific weight, energy efficient buildings are indispensable for reaching a global environmental solution. Moreover, the emission of fine particles (PM2.5 and PM10) from fuel combustion for heat and transportation mostly concentrate in cities.

The construction sector is responsible for 9% of the EU GDP and nearly 15 million direct and indirect jobs. The near totality of the value chain is located in Europe. Specialised construction activities that include renovation work and energy retrofits account for 2/3 of the overall employment in constructions.

Energy renovation of existing buildings is helpful for reducing energy imports, which increased from slightly more than 44% of gross available energy in 1990 to 55.1% by 2017. The building stock plays a major role on gas imports, and an annual retrofit rate of 2% of the EU building stock (together with some electrification of heat demand) would lead to a 25% drop in projected peak monthly gas demand in buildings by 2040[1].

Renovating buildings reduces running costs for citizens and businesses. Vulnerable citizens in Europe are the most severely impacted by the inefficiency of the building stock and rising energy prices. It is estimated that more than 50 million households in the EU experience energy poverty as a result of energy inefficient buildings and appliances, high energy expenditures, low household incomes and specific household needs.

How is Europe looking at its buildings?

Substantial progresses have been made in recent years under the framework of the Energy Performance of Buildings Directive (EPBD) and Energy Efficiency Directive (EED). Nowadays, new buildings tend to operate with less than half of the energy consumed by buildings built 20 years ago. However, approximately 80% of today's buildings will still be in use in 2050 and 75% of this stock is energy inefficient. Current very low energy renovation rates (approximately 1%) across the EU are insufficient to ensure the necessary energy savings and will need to at least double in the coming years to achieve a climate-neutral European Union by 2050.

This very ambitious target has been recently formalised by the European Green Deal (EGD), which aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy, decoupling economic growth from resource use. The EGD foresees to implement the 'Renovation Wave' initiative in the building sector, as set out in the 2020 Commission Work Programme.

In accordance with the Commission's vision, this initiative is an opportunity for scaling up current rates and investigate the possibility of renovation at district and urban scale, which will enable more integrated solutions for renewable energy, like advanced district heating and cooling, waste management, sustainable mobility and social cohesion. Improving energy performance of the existing building stock will support the wide array of sectors and more importantly small and medium-sized enterprises (SMEs) of the construction industry.

What changes after the Covid-19 pandemic?

Covid-19 has created the largest global crisis after the Second World War, sending shock waves through health systems, economies and societies around the world. Suddenly, the majority of European citizens had to change their behaviours, reducing their movements to a minimum and spending almost all their time at home. This had significant repercussions on the energy sector, slowing down transport, trade, and economic activity across countries. As reported by the IEA Global Energy Review 2020[2], countries in full lockdown experienced an average of 25% decline in energy demand per week and countries in partial lockdown an average of 18% decline.

[1] https://www.iea.org/commentaries/a-long-term-view-of-natural-gas-security-in-the-european-union
[2] https://www.iea.org/topics/covid-19

In June 2020, the Global Economic Prospects of the World Bank[3] provided an unfavorable outlook for the near-term. The baseline forecast (which takes into account the fiscal and monetary policy support of governments) envisions the deepest global recession in decades with a 5.2% contraction in global GDP for 2020. Over a longer horizon, the deep recessions the pandemic has triggered are expected to leave lasting scars through lower investment, an erosion of human capital through lost work and schooling, and fragmentation of global trade and supply linkages.

As reported by EUROSTAT[4], in the Euro area the seasonally adjusted GDP decreased by 3.6% and the employment rate decreased by 0.2% during the first quarter of 2020, compared to the previous quarter. The Economic Forecast of spring 2020[5] projects that the euro area economy will contract by a record of 7.75% in 2020 and grow by 6.25% in 2021. The impact on the EU's economy due to the pandemic is uniform across all Member States, but both the drop in output in 2020 and the strength of the rebound in 2021 are set to differ markedly, because of the differences in the economy structures and in the capacity to respond with supporting policies.

The ultimate impact of Covid-19 will depend on questions that do not yet have definitive answers. Like, how quickly will an effective vaccine be developed? Will consumers remain cautious about their safety in public spaces and on public transport? Will governments respond effectively to the pressure to create jobs by supporting green technologies? It will take several months, at least, before we know for sure. However, it is reasonable to believe that an interlocutory phase will take place, during which physical distancing and prudent behaviours continue to apply. This will hinder the return to a massive use of transport and practices such as teleworking and distance learning could contain tertiary consumptions, as well. The only sector with a foreseeable increase in energy consumption is the residential one. Actions focused on this sector are strategic.

A key factor for the transition to greener growth scenarios is oil price. As a result of the reductions in transport, the demand for oil has dropped and it is not foreseen to recover quickly. On one hand, the decrease of energy prices reduces the economic appeal of energy efficiency and renewable technologies, on the other it can drive oil companies to investment elsewhere. Some big European operators have already announced new development strategies, but this is not the case in other parts of the world. Probably, some regions will want to accelerate the energy transition, while others will opt to focus more on developing domestic manufacturing industries and protecting existing energy producers.

To face this perspective, at the end of May 2020 the European Commission put forward its proposal for a major recovery plan, called "Next Generation EU". A new recovery and resilience facility of €560 billion will offer financial support for investments and reforms, including actions in relation to the green and digital transitions, and the Just Transition Fund will be strengthened up to €40 billion, to assist Member States in accelerating the transition towards climate neutrality. Moreover, it is expected that a new strategic investment facility (built into the programme InvestEU[6]) will generate investments of up to €150 billion boosting the resilience of strategic sectors. One of the main objectives is to initiate a massive renovation wave of the existing buildings and infrastructure and a more circular economy and introduce local jobs. Renovation projects can be unrolled quickly and are estimated to account for about 3-4 million workers with around 60% of expenditure on home energy efficiency retrofits going to labour.

Why are the renovation rates still so low?

Over the period 2012-2016, the annual amount of deep energy renovations in the EU was only 0.2% (with relatively small variation between individual Member States), despite the European directives and the transposition policies of the governments.

Many barriers still do not allow to progress through optimal ways. In a recent survey[7], the vast majority of consumers have encountered financial barriers: for 74% of respondents the energy renovations are too expensive and 78% do not like to take loans or mortgages. Interestingly, a high proportion of consumers (about 60%) would not invest because they believe that they will not benefit from it. Tenants are more concerned that benefits will be earned by landlords than the other way around. More than half of the surveyed participants (57%) think that dealing with installers and construction works is unpleasant and time-consuming, and 68% finds the administrative requirements too complicated.

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[3] https://www.worldbank.org/en/news/feature/2020/06/08/the-global-economic-outlook-during-the-covid-19-pandemic-a-changed-world

[4] https://ec.europa.eu/eurostat/documents/2995521/10294996/2-09062020-AP-EN.pdf/8a68ea5e-5189-5b09-24de-ea057adeee1 5

[5] https://ec.europa.eu/commission/presscorner/detail/en/ip_20_799

[6] https://ec.europa.eu/commission/priorities/jobs-growth-and-investment/investment-plan-europe-juncker-plan/whats-next-investeu-programme-2021-2027_en

[7] https://ec.europa.eu/energy/sites/ener/files/documents/1.final_report.pdf

Consumers with a lower income more frequently experience administrative and regulatory barriers to investing in energy renovations. They are also more sceptical towards energy-related works and the reliability of building professionals. Administrative and financial barriers are most often perceived in south and eastern Europe. These regions also have a higher number of citizens who consider regulation requirements too strict or excessive.

A clear and consolidated legislative horizon, as well as precise and easily understandable information on existing and forthcoming financing mechanisms are often missing. To overcome the lack of experience in underwriting energy efficiency loans and standardised evaluation methods for measuring and verifying energy savings, Member States recently updated their Long-Term Renovation Strategies (LTRS). The new updated roadmaps for 2030 with a view to 2050 should reduce the risky perception of building owners and provide standard solutions for more disadvantaged citizens. This would also create favourable conditions for introducing more stringent requirements and forms of refurbishment obligation associated to trigger events (e.g. the sale, rental or lease of a building or a disaster/incident due to fire, earthquake or flood). Some Member States are following this path.

Why is the regional scale important?

While the requirement to ensure a harmonious and balanced development of the Community area, by narrowing the gaps between certain regions, was initially taken into consideration in 1957 with the signing of the Treaty that established the Economic European Community, it has been increasing in importance since the EU enlargement in 2004. This is not just a theoretical principle motivated by the core values of the Union, it is rather a necessary condition for the sustainable development throughout Europe. In fact, given the interdependence of the EU economies, the dynamics of the development in each Member State also affect the growth of the others, and the same goes for regions within countries.

In the EU, the development regions are considered as a factor promoting the structural policies and they are the direct beneficiaries of the Structural Funds, from which the development programs implemented at inter-regional level are funded. In the scenario that is emerging after the Covid-19 pandemic, the importance of actions taken at region level is likely to grow further. In fact, given the jurisdiction that regional governments have in some areas, it is often possible to give more effective and quicker answers to urgent needs at this level.

The EU created a unitary reference base of the regional policy, called the Nomenclature of Territorial Units for Statistics (NUTS). This classification lists 104 regions at NUTS 1, 283 regions at NUTS 2 and 1345 regions at NUTS 3 level. The regional development policy in the EU Member States is implemented at NUTS2 level, but NUTS3 regions are also taken into account for specific socio-economic diagnoses.

Regionally tailored energy renovation action is needed to improve citizens' quality of life throughout the EU territory. In Member States with per capita GDPs below the EU average, 20% of low-income families live in rural areas. Also, it is these countries that have the highest proportions of owner-occupiers (e.g. 97% in Romania). In some cases, energy accounts for almost 20% of total household expenditure.

What will you find in this report?

With this report, we want to provide clear indications and datasets that can support European and national decision-making processes focused on the definition of fine-tuned programmes for the refurbishment of existing buildings. Simplifying in one-shot question, where does it makes sense to invest to increase the renovation rates?

Chapter 2 includes a collection of maps describing the regional residential building stocks. Chapter 3 discusses the energy saving potential associated to existing buildings at NUTS2 level. Chapter 4 discusses further options to generate data at local level.

2 Key characteristics of the regional building stocks

This section provides an overview of indicators which affect the energy consumptions of existing buildings at regional level (NUTS2 and/or NUTS3), and which can play a role for the definition of energy efficiency policy measures and investment plans. In particular, some maps of the EU regions are shown for:

- The climate conditions, which strongly influence the energy demand for heating and cooling.
- The age of buildings (based on the year of construction), which is a simple indicator of the status of the building stocks.
- The type of building and ownership, from which the importance of the 'split incentive' barrier depends.
- The economic well-being over the period 2018-2021, which is a good indicator of the investment capacity in energy renovation.

2.1 Climate conditions

The energy consumptions for keeping homes warm in winter and cool in summer depend on the regional climate but also on many other factors, such as the amount of sunlight, the height above sea level, the shape of the land and the distance from seas. The quantity of energy used to express the cooling or heating needed is based on the so-called Heating and Cooling Degree Days (HDD and CDD). This quantity, also used to calculate the energy demand of buildings, expresses the number of degrees to add to or subtract from the outside temperature for all days of the heating/cooling periods to reach indoor comfort conditions.

To generate the following maps (Figure 1-Figure 4), we referred to the Typical Meteorological Years (TMY) delivered by the PVGIS[8] tool of the JRC. TMYs are based on satellite derived solar radiation data and other meteorological parameters obtained from reanalysis products (Huld et Al. 2018).

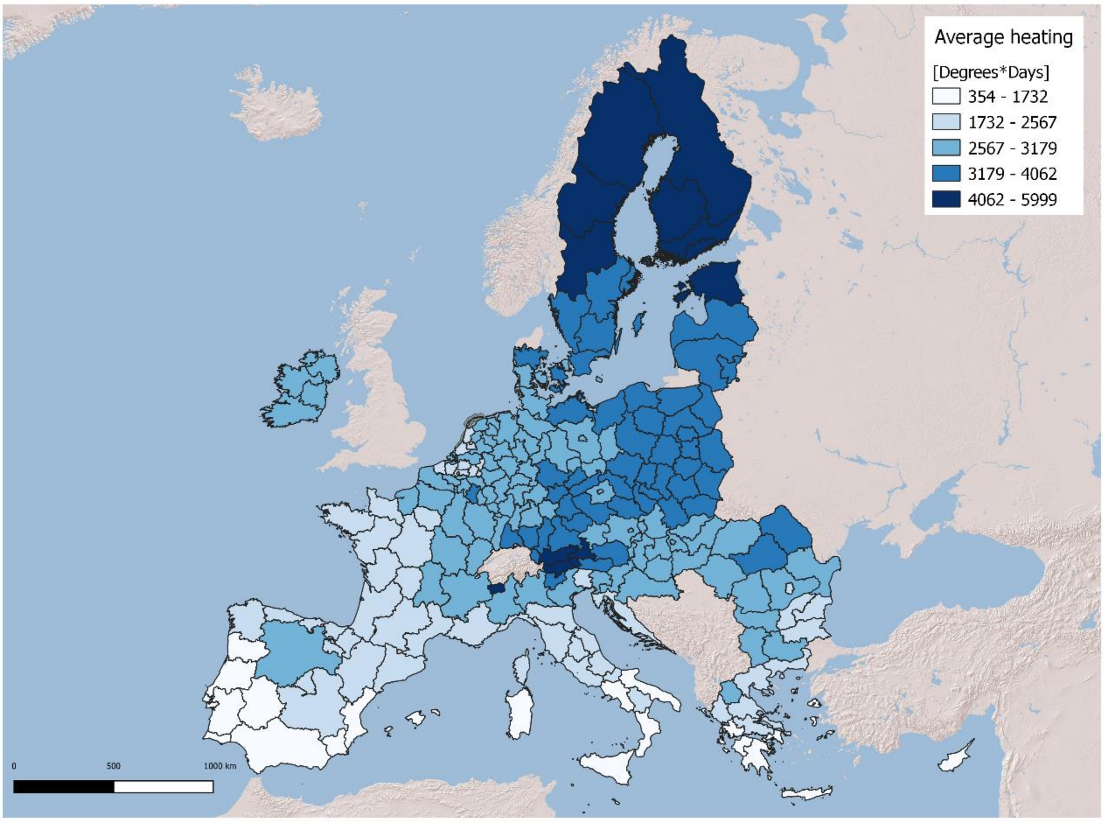

Figure 1. Heating Degree Days at NUTS2 level (PVGIS).

[8] https://ec.europa.eu/jrc/en/PVGIS/tools/tmy

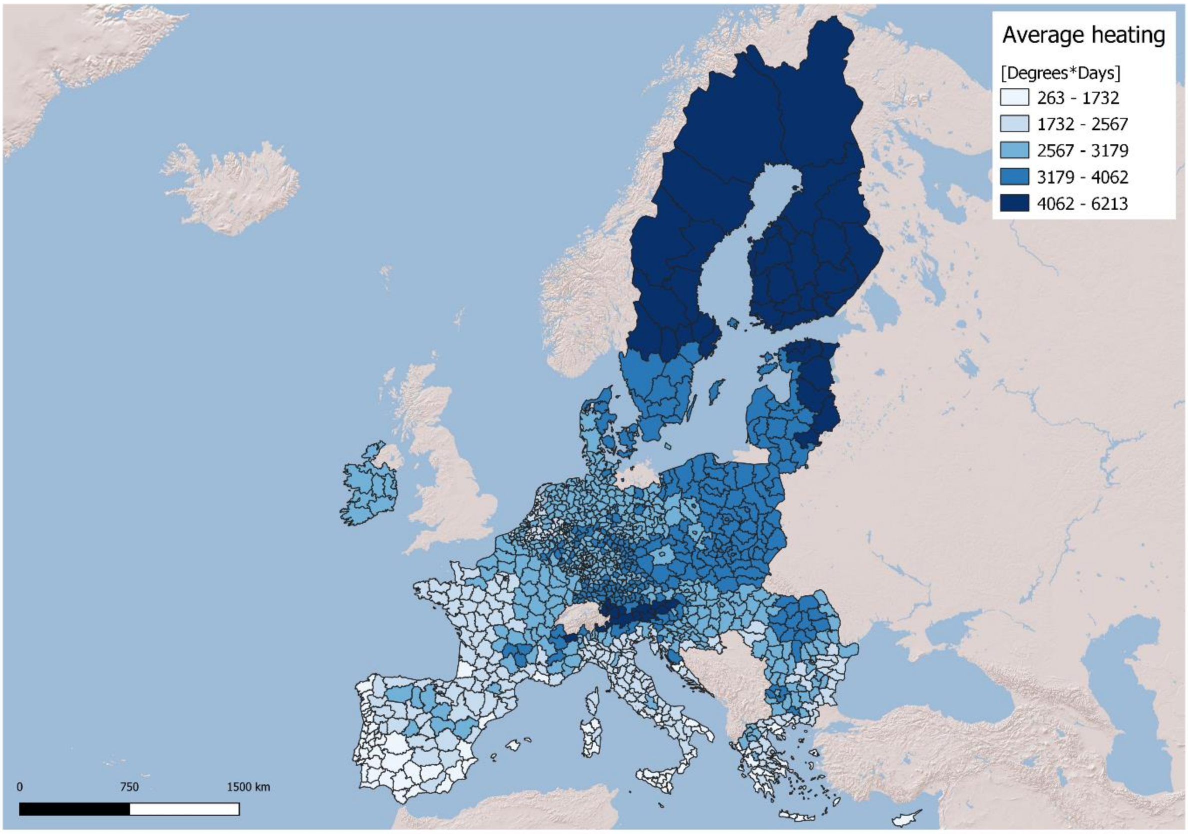

Figure 2. Heating Degree Days at NUTS3 level (PVGIS).

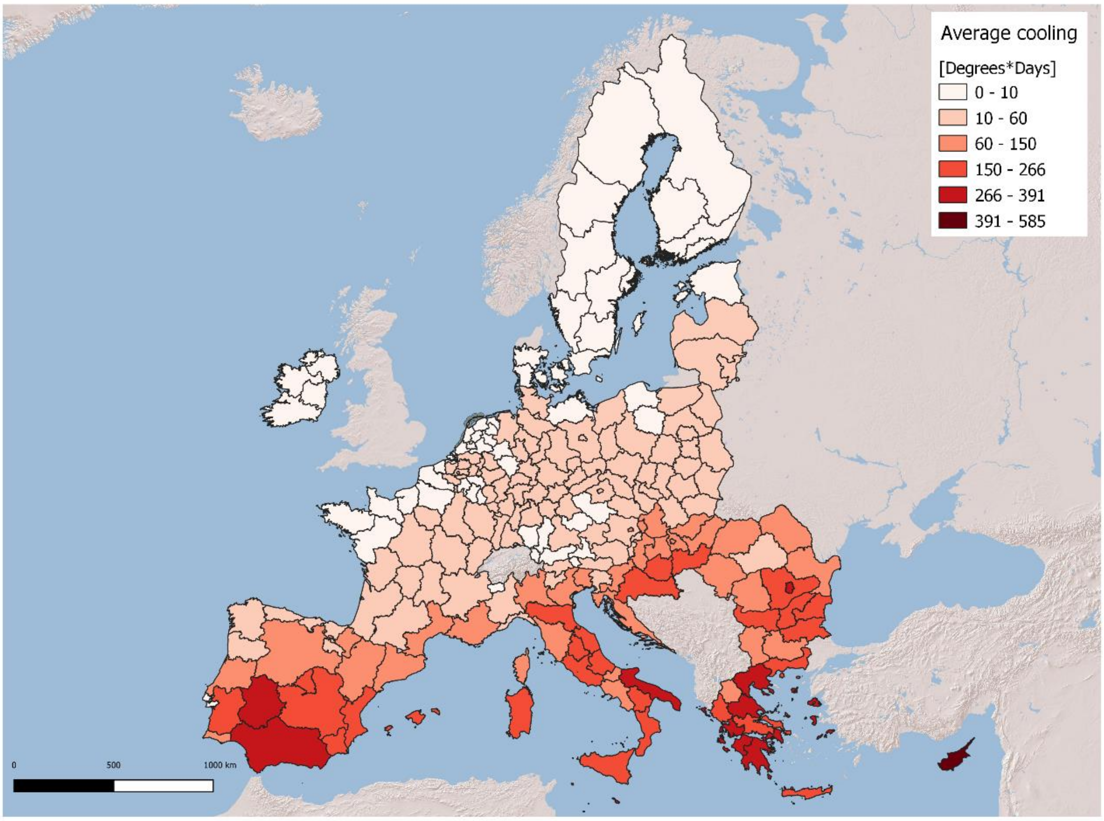

Figure 3. Cooling Degree Days at NUTS2 level (PVGIS).

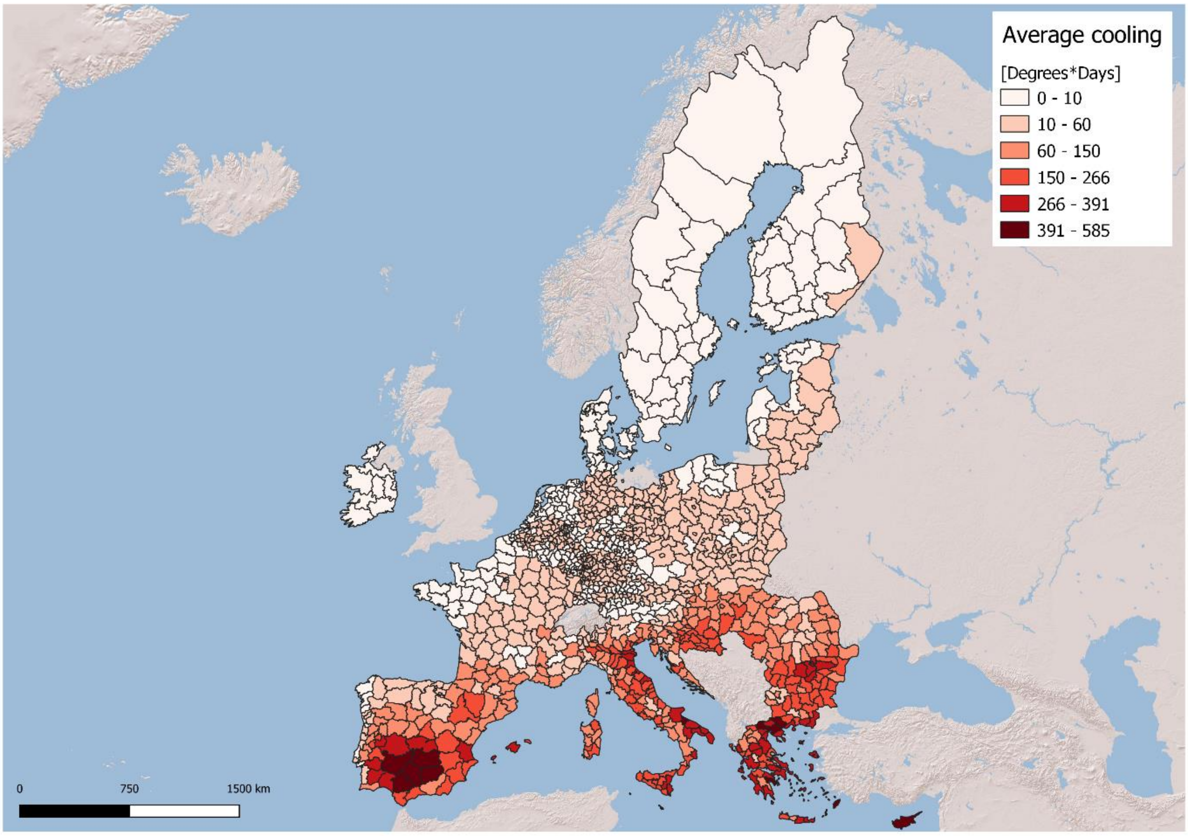

Figure 4. Cooling Degree Days at NUTS3 level (PVGIS).

These maps confirm the common classification of European climate, which is mainly oceanic, Mediterranean or continental (in accordance with the Köppen climate classification). Most of western Europe (which is strongly conditioned by the Gulf Stream) has an oceanic climate, which normally feature cool summers and cool winters. Southern Europe has a Mediterranean climate, featuring hot summers and warm winters. Central-eastern Europe is classified as having a continental climate, with warm summers, cold winters, and wide-ranging annual temperatures.

2.2 Buildings' age

The average age of existing buildings and the share of old buildings in the total stock are good indicators of the average efficiency of the building stock: the higher the share of dwellings built before the introduction of efficiency standards (i.e. before 1990), the lower the energy performance of the stock. The share of aged building (built before 1920) is also interesting because it provides the weight of historical buildings, which normally presents more refurbishment limits.

The maps below are based on the data published in the 2011 Census Hub[9] of EUROSTAT, opportunely updated by down-scaling the national constructions after 2011, taken from the Building Stock Observatory[10] of the EC.

The analysis of the average age of existing buildings (Figure 5 and Figure 6) reveals that the most critical regions (i.e. with lower average age) are those of north-east Germany, south Belgium, central France and north-west Italy. The percentage of occupied building built before 1990 (Figure 7 and Figure 8) is higher in the north-east regions (i.e. in Sweden, Estonia, Latvia, Lithuania, Hungary, Romania, and Bulgaria), while the share of historical buildings, built before 1920 (Figure 9 and Figure 10), is higher in central Europe (i.e. in Belgium, France and Germany).

[9] https://ec.europa.eu/eurostat/web/population-and-housing-census/census-data/2011-census
[10] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/eu-bso_en

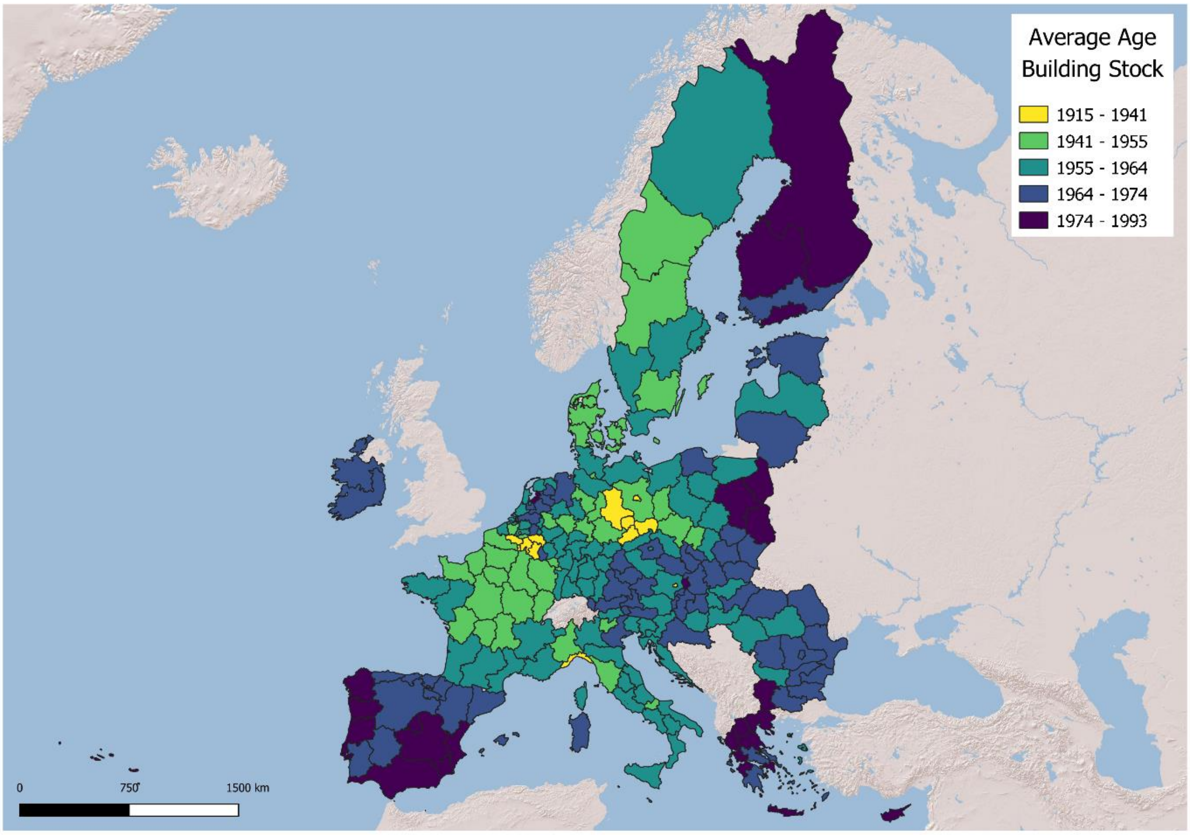

Figure 5. Average age of building stock at NUTS2 level (JRC elaborations on CENSUS HUB data).

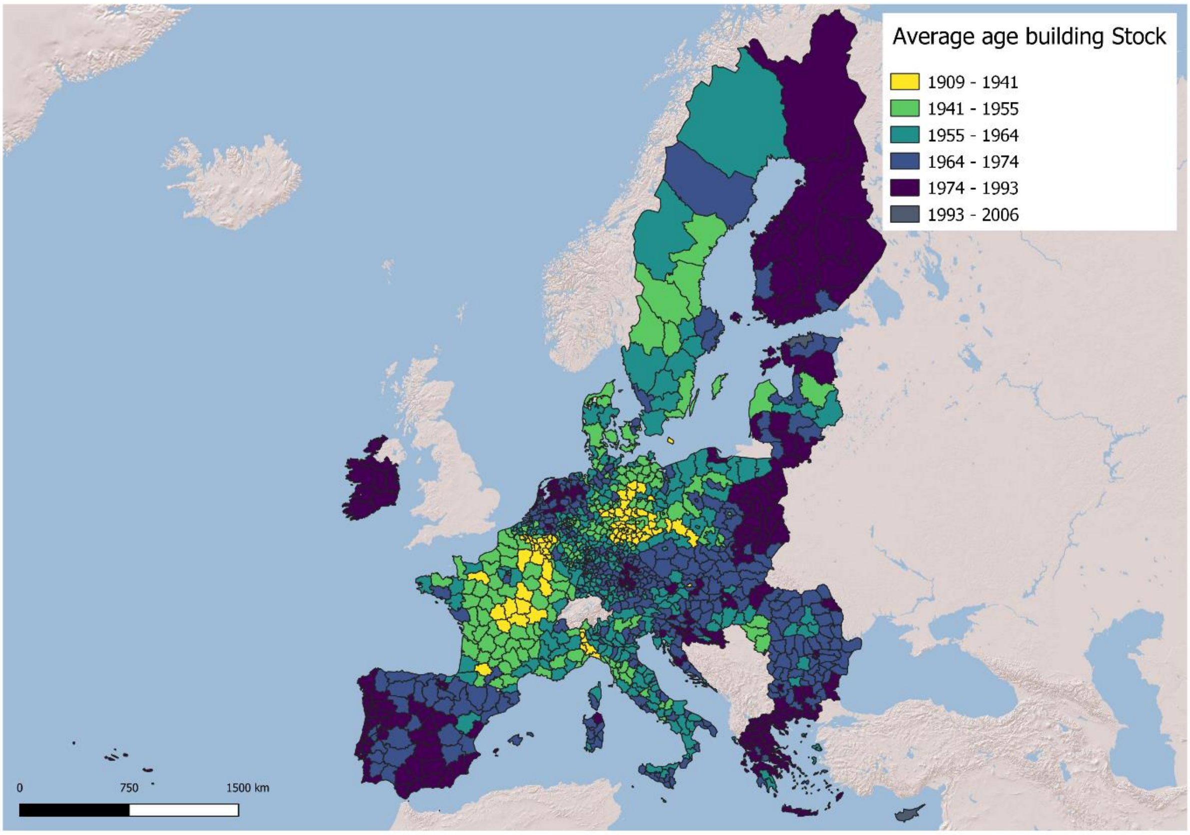

Figure 6. Average age of building stock at NUTS3 level (JRC elaborations on CENSUS HUB data).

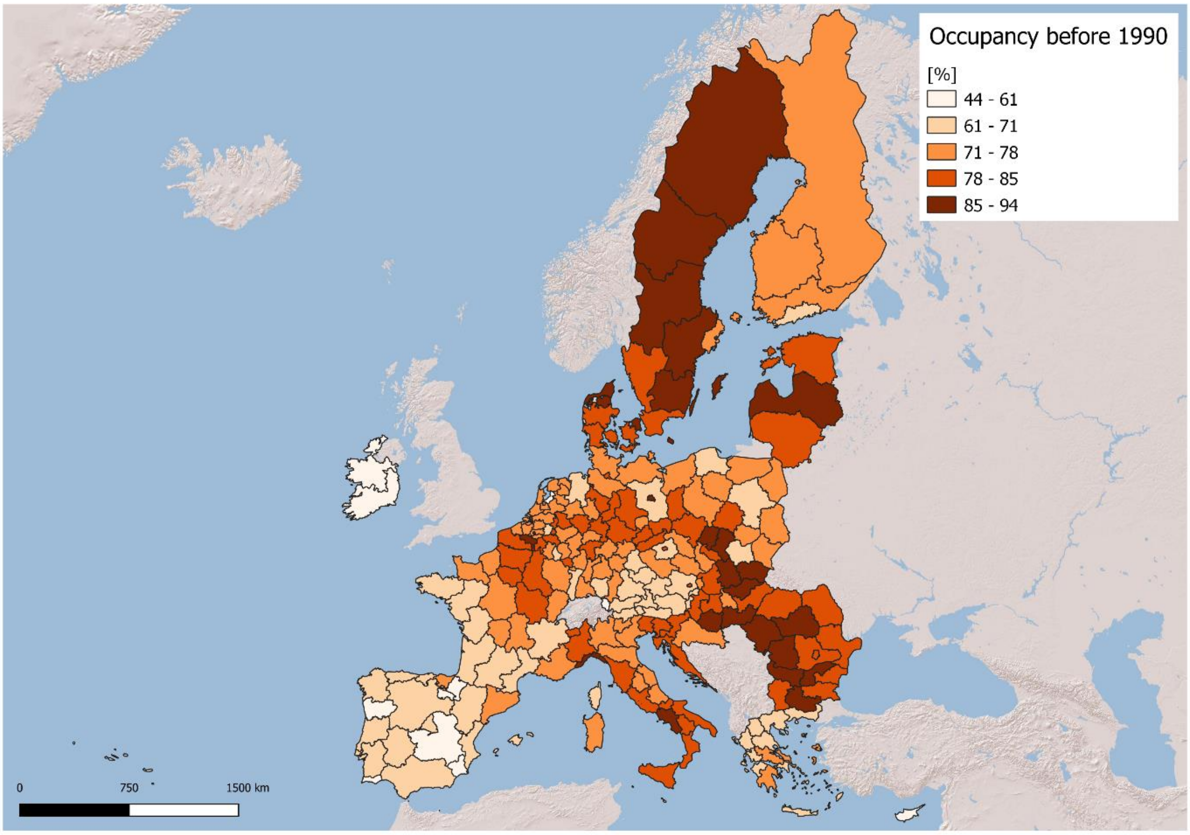

Figure 7. Percentage of occupied building built before 1990 at NUTS2 level (CENSUS HUB).

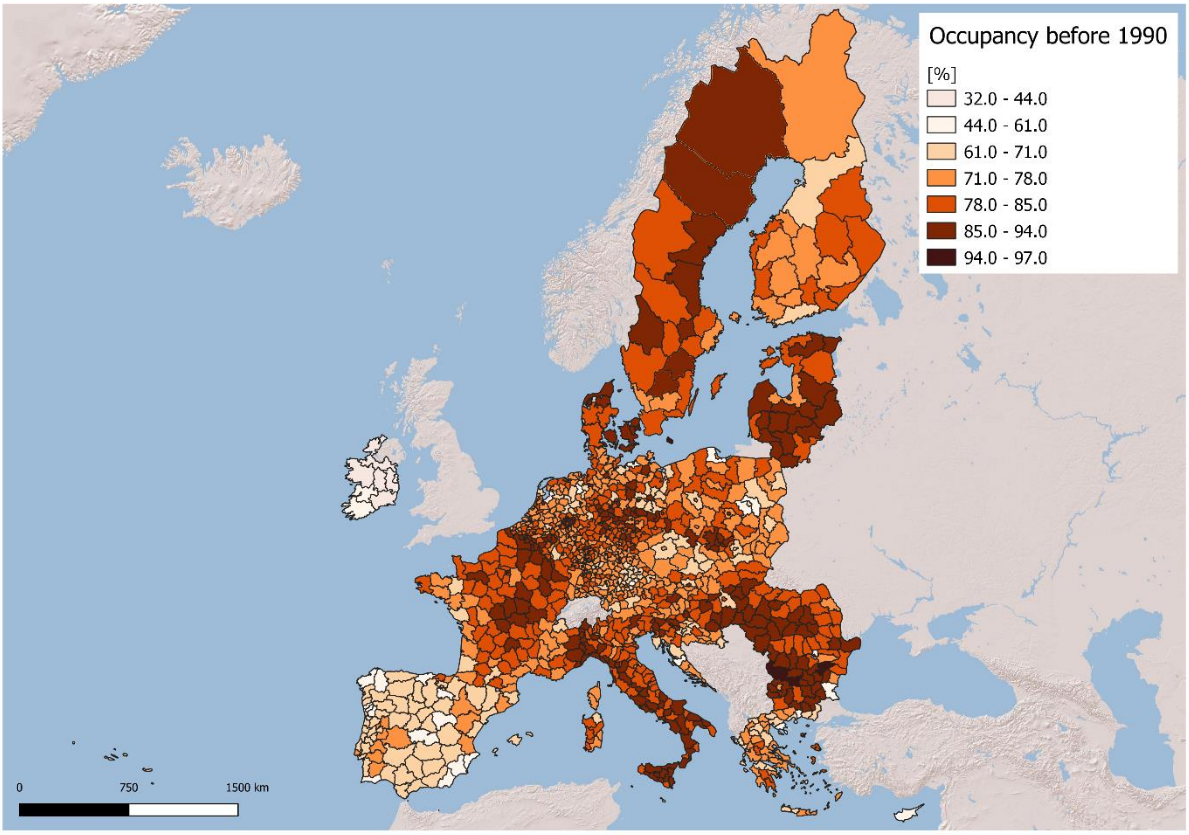

Figure 8. Percentage of occupied building built before 1990 at NUTS3 level (CENSUS HUB).

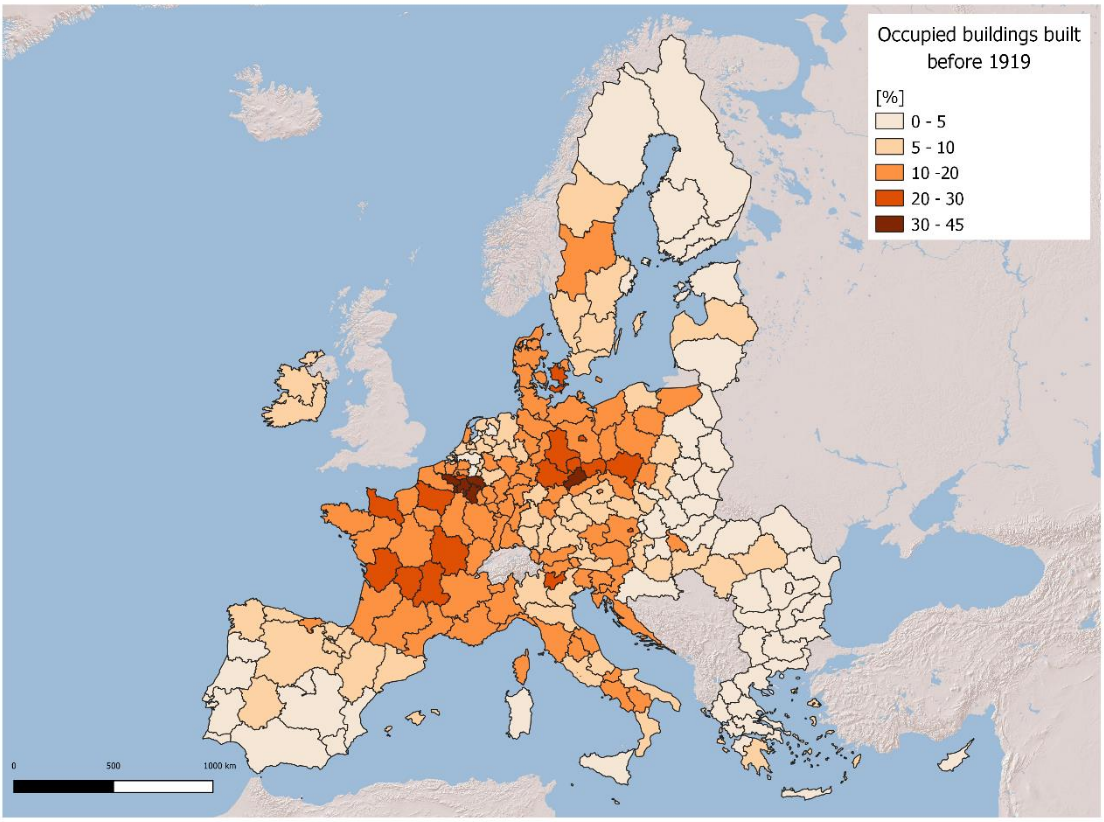

Figure 9. Percentage of occupied building built before 1920 at NUTS2 level (CENSUS HUB).

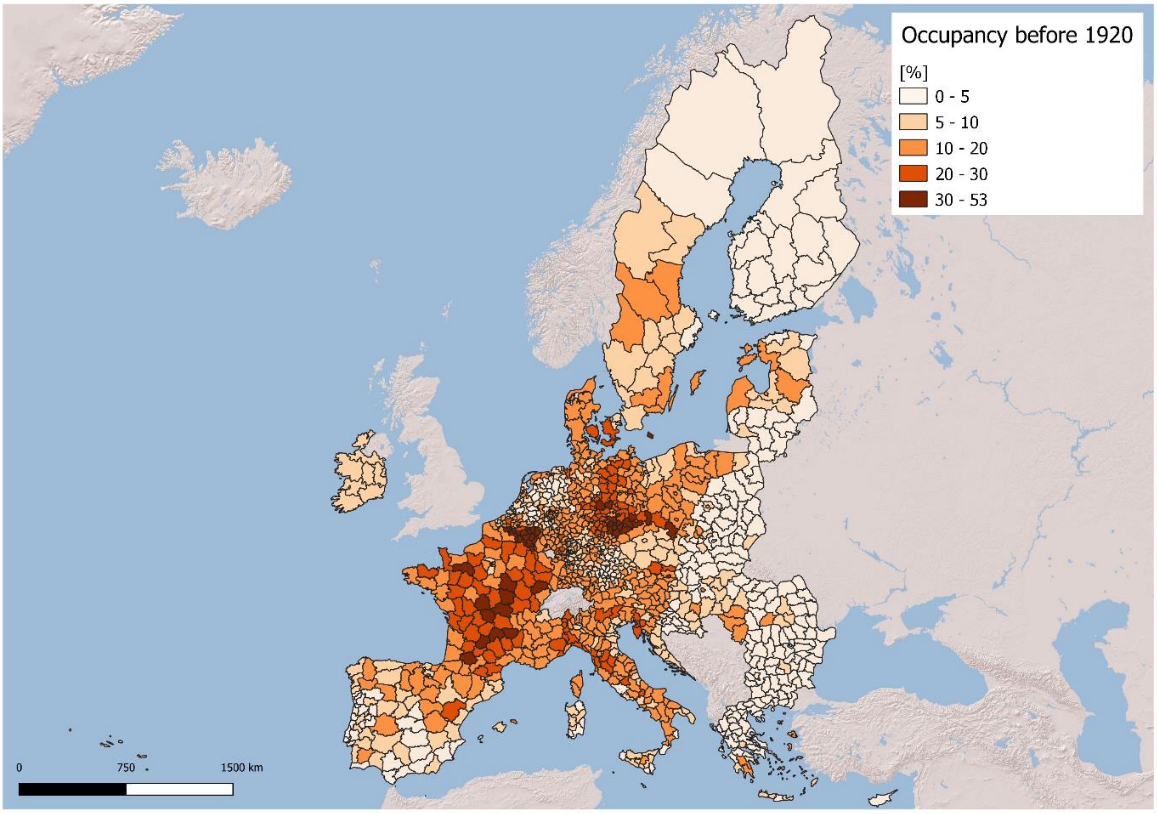

Figure 10. Percentage of occupied building built before 1920 at NUTS3 level (CENSUS HUB).

2.3 Building type and ownership

The presence of split incentives inhibits the deployment of energy efficiency upgrades in various segments of the building sector. This financial barrier is typical of rented homes, where the recovery cost issues of refurbishment investments often arise. This is due to the failure of distributing effectively expenses and gains between concerned actors, with more complications in multi-apartment buildings and social housing units (Economidou, 2015).

Hence, it is interesting to observe that at regional level the shares of total non-owner occupied dwellings (Figure 11) and of rented multi-family buildings (Figure 12). The higher the percentages, the more relevant the split incentive barriers are. From this point of view, the biggest challenges are in the urban areas of north-central Europe, such as Stockholm, Berlin, Hamburg, Prague and Wien.

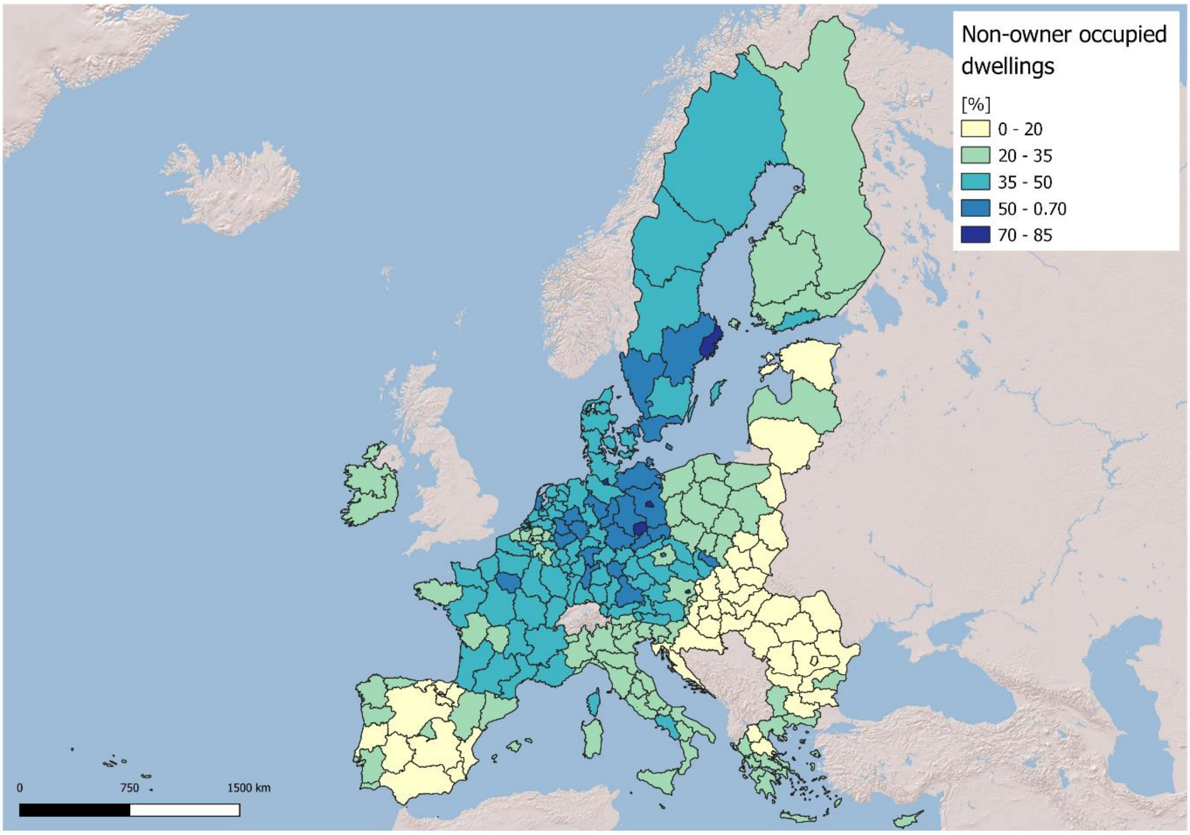

Figure 11. Percentage of non-owner-occupied dwellings at NUTS2 level (CENSUS HUB).

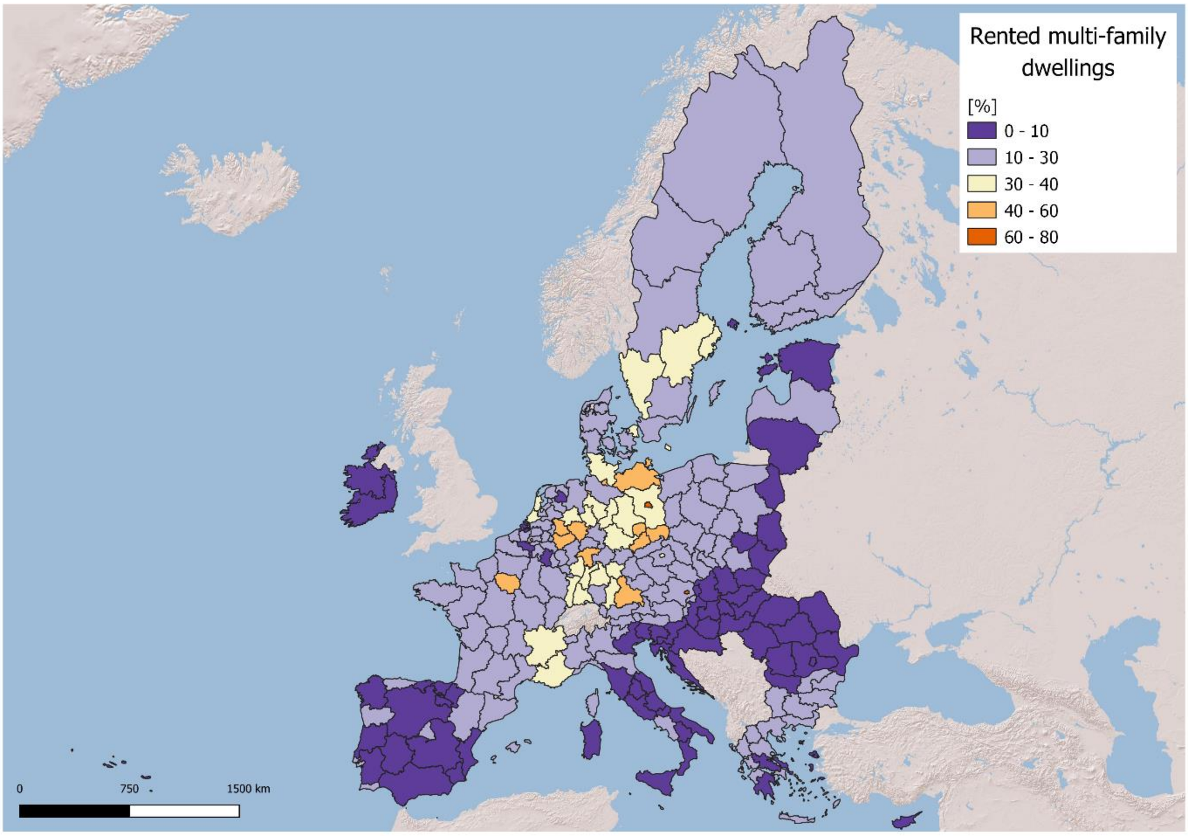

Figure 12. Percentage of rented multi-family dwellings at NUTS2 level (CENSUS HUB).

2.4 Economic well-being

As discussed in Chapter 1, one of the main barriers to building refurbishment is the financial one. The investments needed to deeply renovate a home are not affordable for all the citizens and a general context of economic incertitude can cause owners to desist from substantial expenses. As the short-term outlook is negative, especially since the Covid-19 pandemic, the system will have to be further supported in a vigorous way and public investment will have to focus on the most disadvantaged sectors.

Taking as reference the Spring 2020 Economic Forecast of the Commission[11] and the regional breakdown of EUROSTAT[12], we derived the following NUTS2 indicators:

- Average GDP per inhabitant in Purchasing Power Standard (PPS) over the period 2018-2021 (Figure 13).
- Variation of the GDP per inhabitant in PPS over the period 2018-2021 (Figure 14).
- Average unemployment rate over the period 2018-2021 (Figure 15).
- Average net disposable income of households per inhabitant in PPS over the period 2018-2021 (Figure 16).
- Average net disposable income of households per inhabitant in PPS received by the 20 % of the population with the lowest income, over the period 2018-2021 (Figure 17).

Then, based on these, we calculated a synthetic indicator of economic well-being over the period 2018-2021 (Figure 18) in order to have a homogeneous indicator to compare all the EU regions and identify the most critical cases.

[11] https://ec.europa.eu/info/business-economy-euro/economic-performance-and-forecasts/economic-forecasts/spring-2020-economic-forecast-deep-and-uneven-recession-uncertain-recovery_en

[12] https://ec.europa.eu/eurostat/cache/metadata/en/reg_eco10_esms.htm

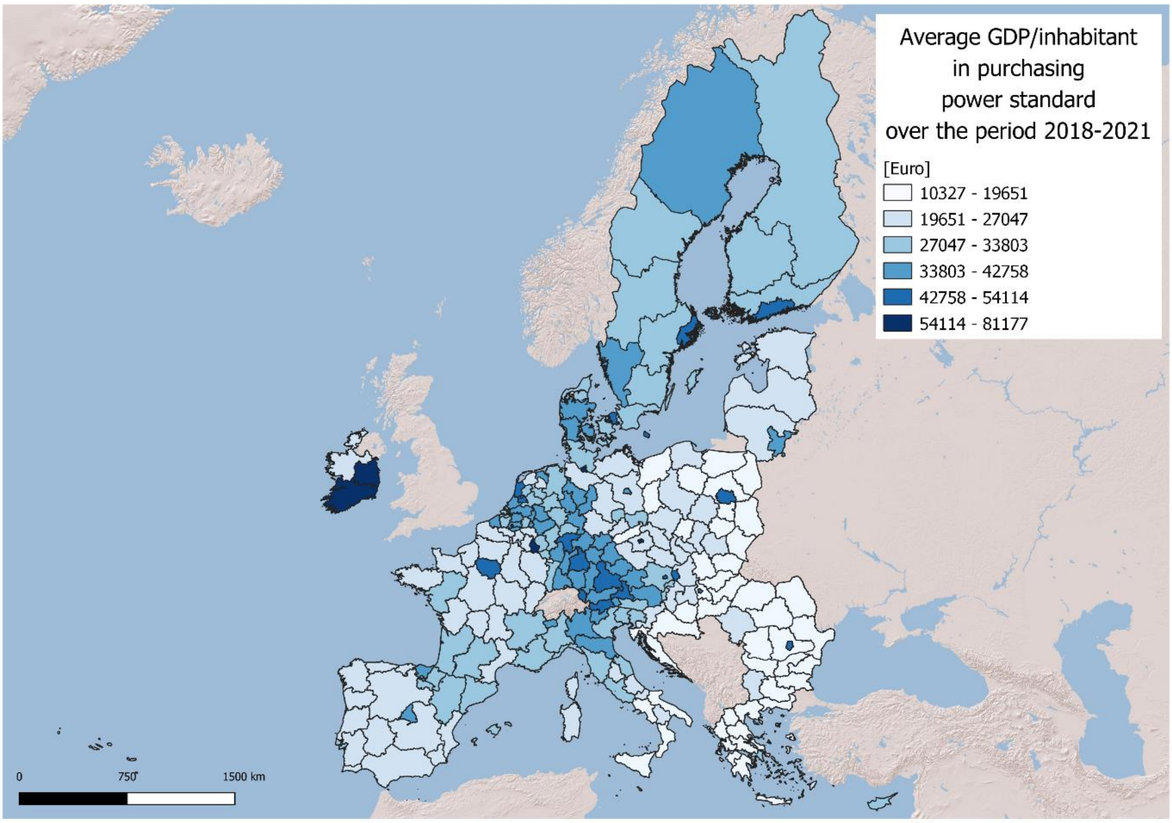

Figure 13. Average GDP per inhabitant in Purchasing Power Standard (PPS) over the period 2018-2021 (JRC elaborations on ESTAT data).

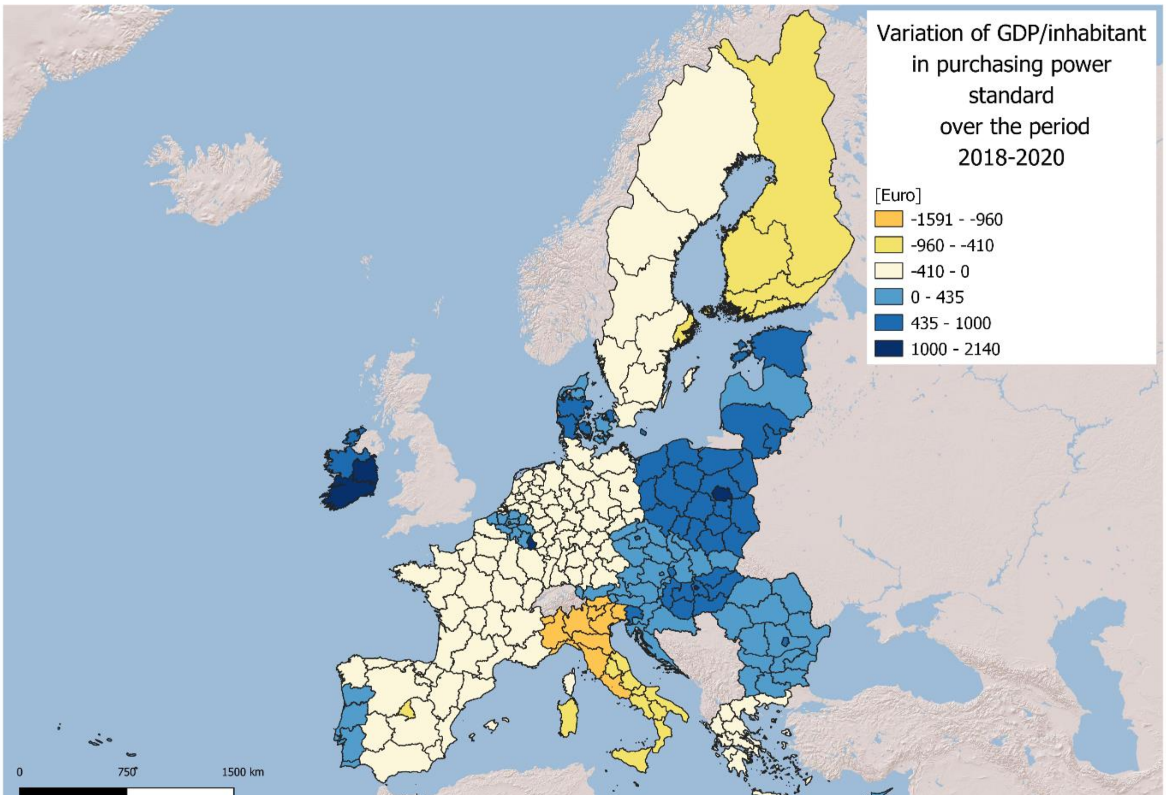

Figure 14. Variation of GDP per inhabitant in purchasing power standard (PPS) over the period 2018-2021 (JRC elaborations on ESTAT data).

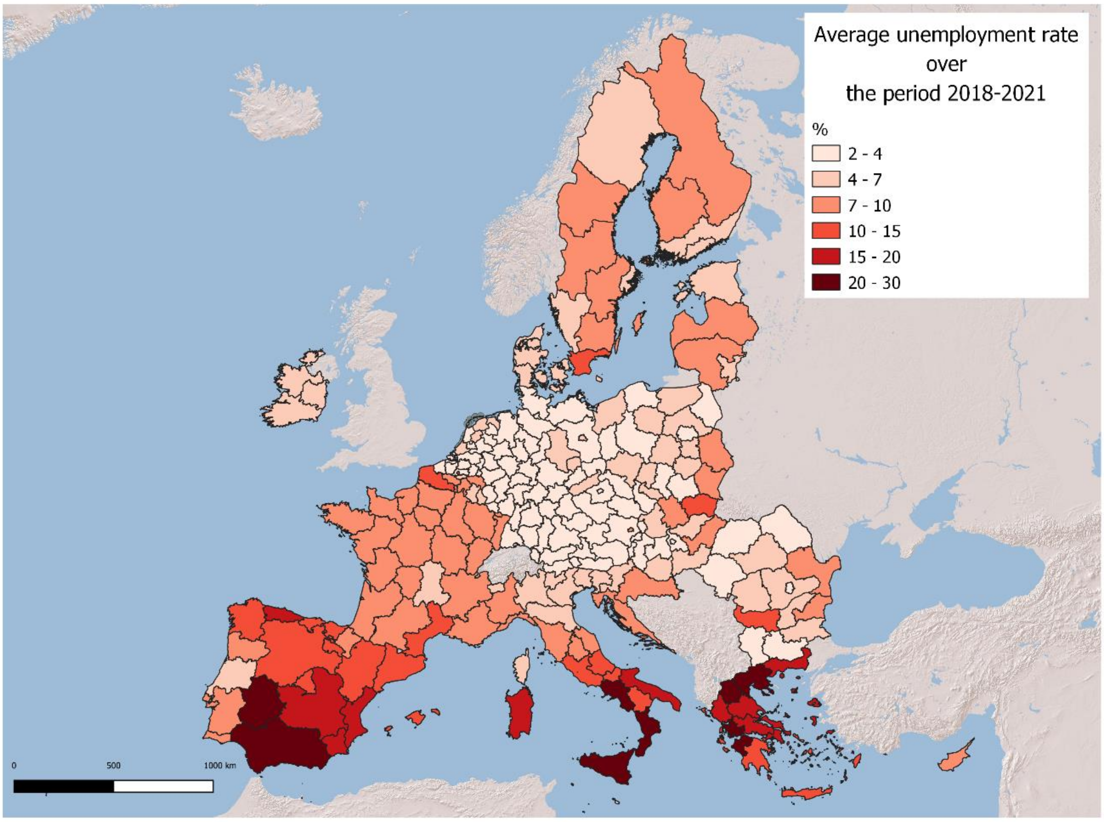

Figure 15. Average unemployment rate over the period 2018-2021(JRC elaborations on ESTAT data).

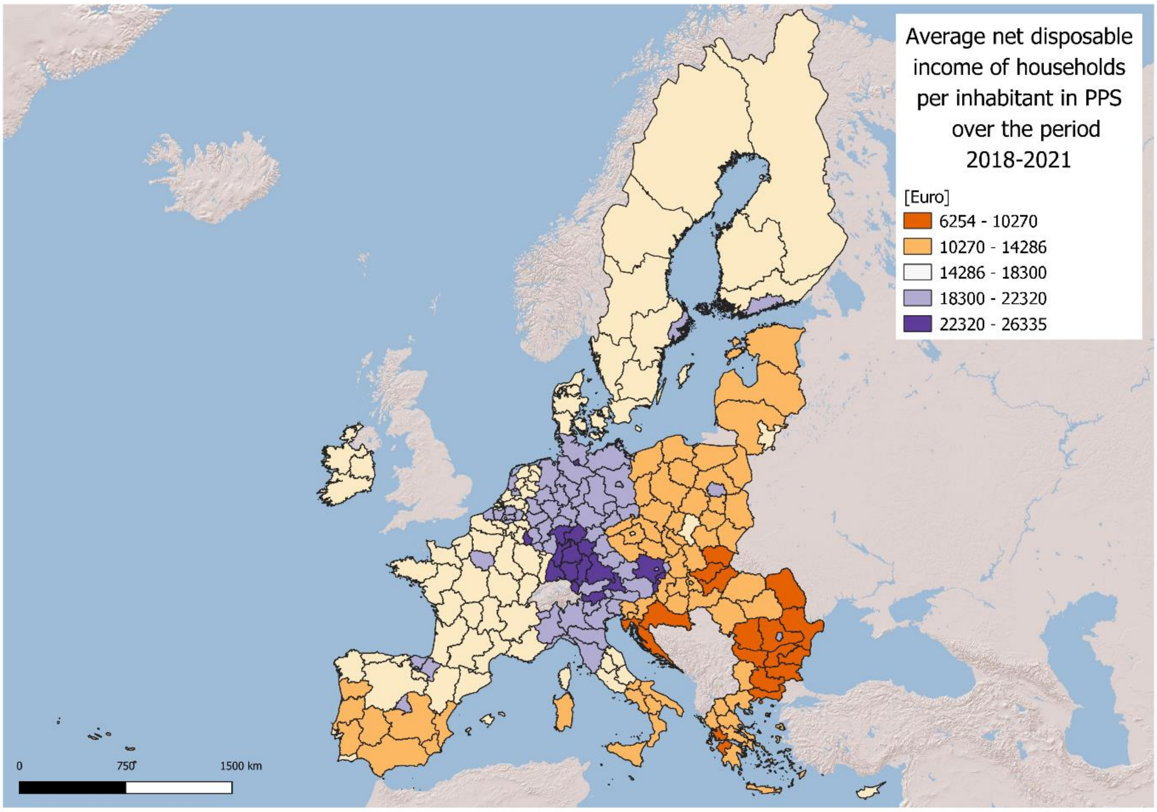

Figure 16. Average net disposable income of households per inhabitant in PPS over the period 2018-2021 (JRC elaborations on ESTAT data).

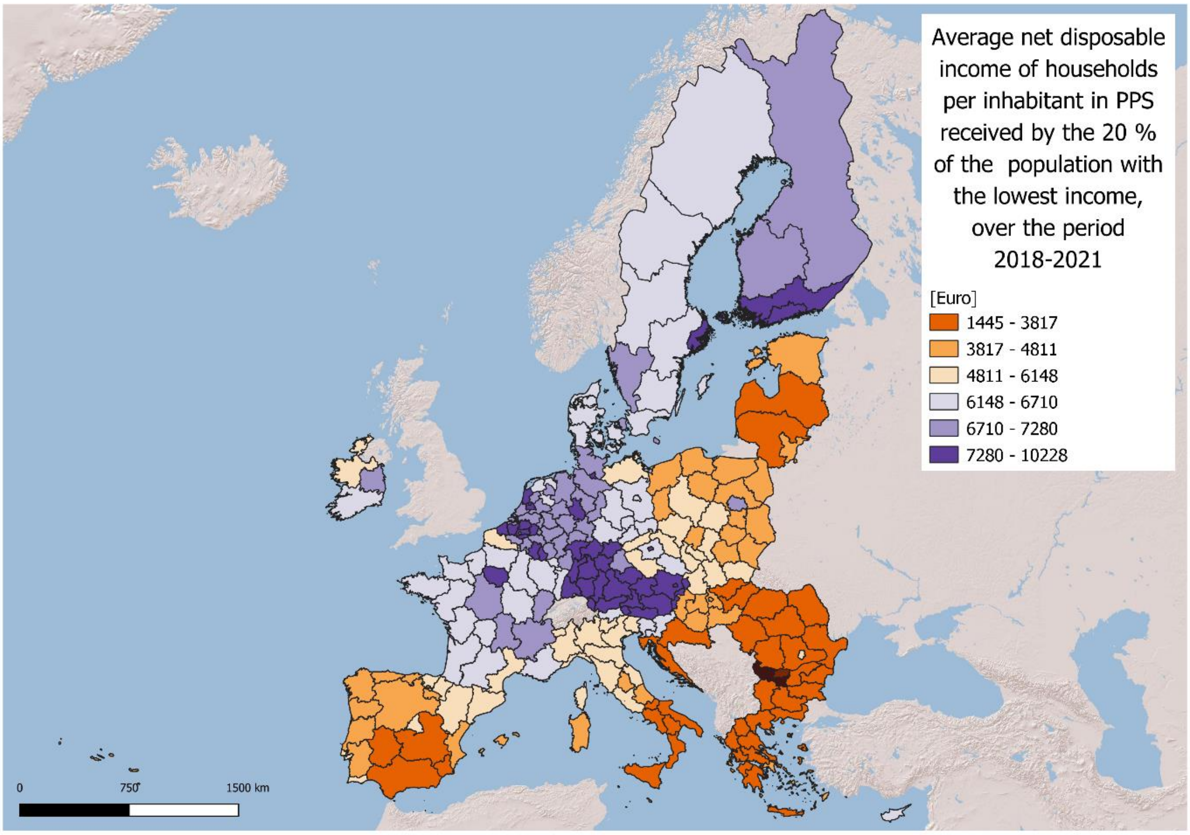

Figure 17. Average net disposable income of households per inhabitant in PPS received by the 20 % of the population with the lowest income, over the period 2018-2021 (JRC elaborations on ESTAT data).

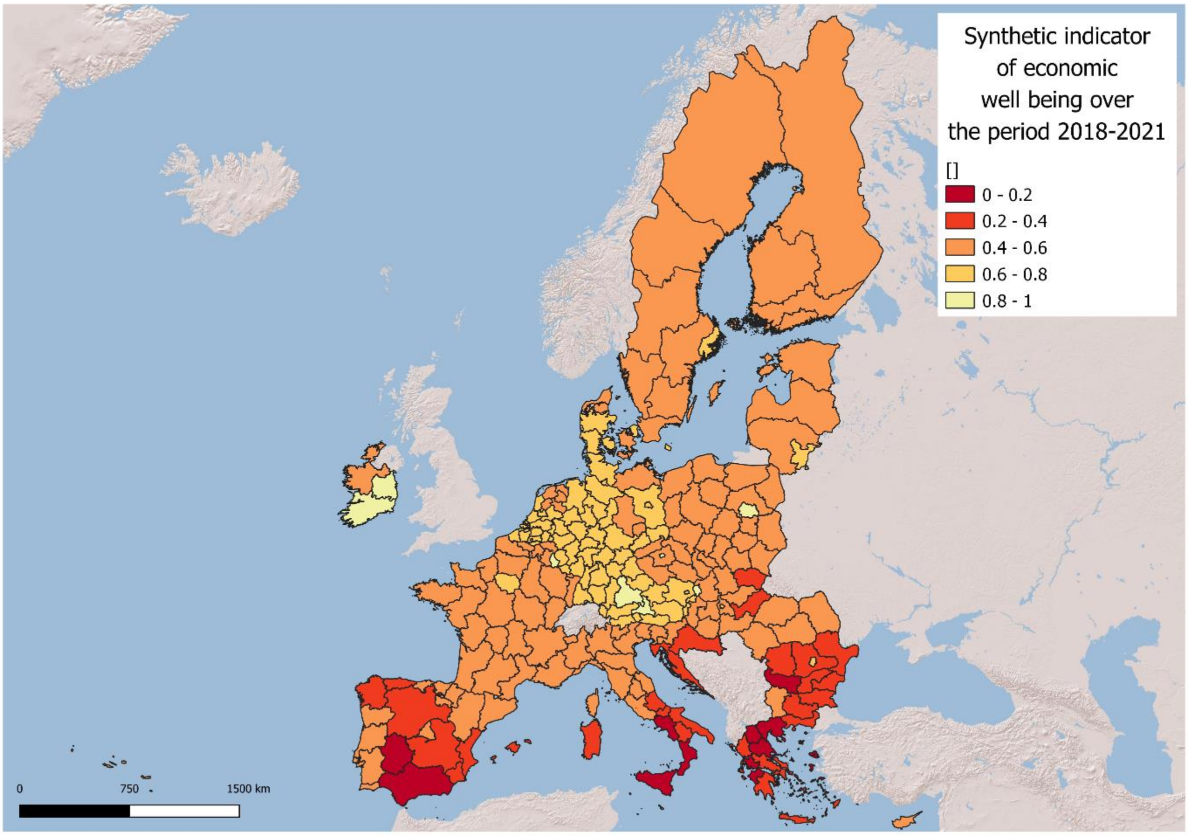

Figure 18. Synthetic indicator of economic well-being over the period 2018-2021 at NUTS2 level.

Based on these indicators, these general conclusions can be derived:

- The lower values of average GDP per inhabitant in the period 2018-2021 are observed in the rural regions of southern and eastern Europe.
- The regions of north Italy are those with a greater negative variation of the GDP per inhabitant over the 2018-2021 period. Also, the other Italian regions, along with the Finnish and a couple of Spanish ones will face a deep recession.
- The average unemployment rate is expected to be higher (over 20%) in the southern regions of Spain and Italy, and in Greece.
- The average net disposable income of households (per inhabitant) is very low in all southern and eastern regions.
- The synthetic indicator suggests that, from an economic point of view, the overall picture is quite negative, and the most critical regions are those in the South Spain (i.e. Extremadura and Andalucía), South of Italy (i.e. Calabria, Sicilia, Campania), Greece (i.e. Sterea Ellada, Makedonia, Aigaio), and Bulgaria (i.e. Severozapaden).

2.5 Composite index

Considering that composite indicators are a risky tool, which may also invite drawing simplistic policy conclusions (if not used in combination with the indicators on which it is built), we generated a map combining all the pre-mentioned information. The procedure is as follow:

- selection of weights for each indicator;
- normalisation of weights;
- linear aggregation of weighted indicators.

For the weights, we decided to prioritise as below:

- Buildings' age: 35% (of which 15% associated to the number of dwellings built before 1991, 15% to the average age of dwellings and 5% to the number of historical dwellings);
- Economic well-being: 30%;
- Heating Degree Days: 25%;
- Non-ownership: 10% (of which 5% associated to the share of non-owner occupied dwellings and 5% to the share of rented multi-family dwellings).

Therefore, the map that we obtained (Figure 19) describes the overall regional criticality of the key aspects affecting the energy consumption of residential buildings. As it can be observed, critical conditions (i.e. index greater than 0.6) exist in many European regions from south to north and from east to west. However, only 11 regions obtained an index greater than 0.8. They are:

- Région De Bruxelles-Capitale and Prov. Hainaut in Belgium;
- Severozapaden in Bulgaria;
- Berlin in Germany;
- Voreio Aigaio in Greece;
- Liguria, Campania, Puglia, Calabria and Sicilia in Italy;
- Wien in Austria.

Not all these regions can be considered particularly homogeneous, and it is evident that different conditions brought to the final value. On one hand, the Italian, Greek and Bulgarian regions represent a particularly critical economic context; on the other, Bruxelles, Berlin and Wien represent metropolitan areas in cold climates (where normally the average age of buildings is lower, and the share of rented apartments is higher than elsewhere). Thus, it seems obvious that to improve the performance of buildings, different situations call for different solutions.

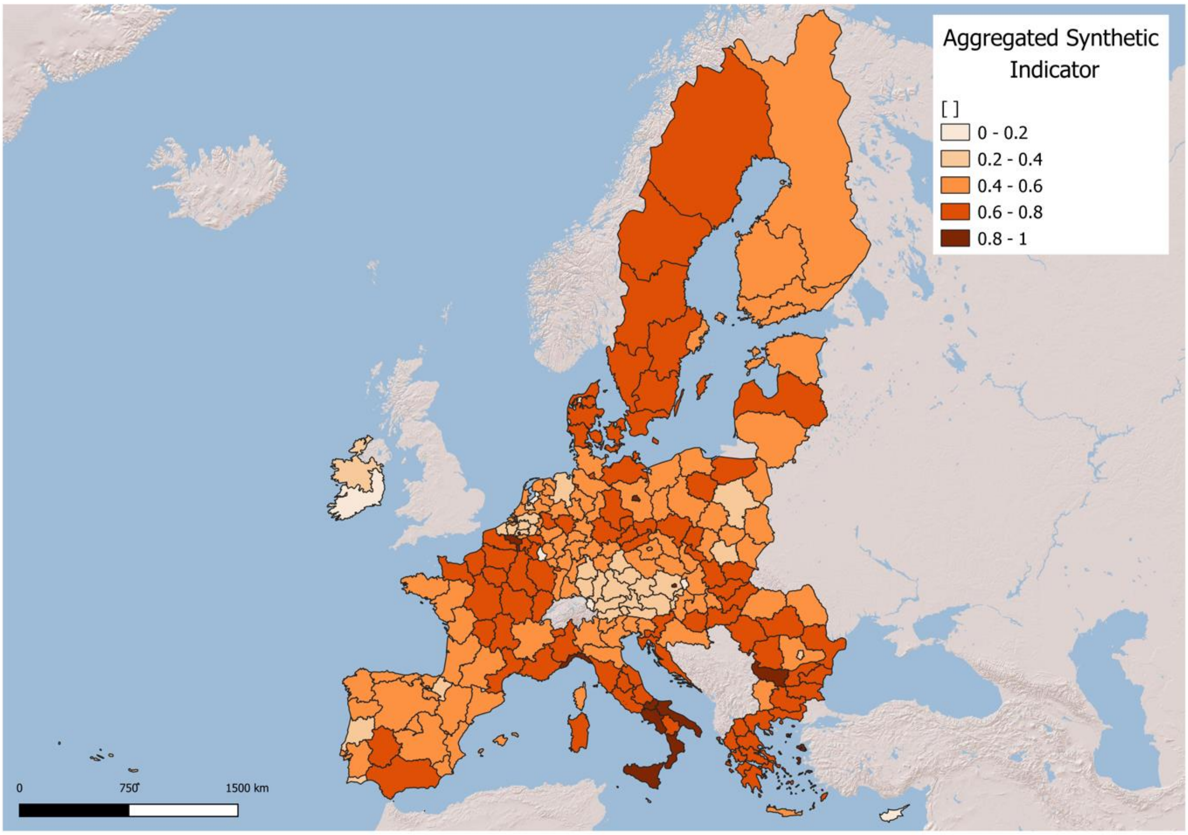

Figure 19. Aggregate synthetic indicator reflecting the regional criticality, under our lens.

3 Energy saving potential and other benefits

In the frame of the implementation of the European Directive 2010/31/EU (EPBD recast of the European Parliament, 2010), EU Member States were asked to develop policies appropriate to their national situations and provide necessary financing to foster the transition to Nearly Zero-Energy Buildings (NZEB). The EPBD recast requires that all new buildings occupied and owned by public authorities are NZEBs from 2019 onwards and all new buildings by the end of 2020. However, acknowledging the variety of building culture and climate throughout Europe, the EPBD does not prescribe a uniform approach for implementing NZEB. Member States were required to draw up National Plans for increasing the number of NZEBs, with targets that may differ for each building category. According to paragraph 3 of Article 9, these plans shall include NZEB definitions reflecting national, regional or local conditions, and numerical indicators of primary energy use and ratio covered by Renewable Energy Systems (RES) (D'Agostino, 2016).

Moreover, the EPBD recast requested Member States to calculate cost-optimal levels of minimum energy performance requirements for new and existing buildings by using the comparative methodology framework established by the Commission with the Delegated Act No. 244/2012 (European Parliament, 2012a) of 16 January 2012 (including explanatory guidelines). The cost-optimal calculation framework involves the following steps: i) definition of national reference buildings representing national building stock; ii) identification of energy efficiency measures and packages to be evaluated; iii) calculation of primary energy demand of the reference buildings with the identified energy efficiency measures; iv) calculation of global costs related to each energy efficiency measure and package, considering long-term expenditures and savings during the calculations period; v) sensitivity analysis for input data; vi) derivation of cost-optimal levels of energy performance requirements.

While Member States are updating their plans and calculations (Boermans, 2015), in line with the regulatory background, a recent research project (ENTRANZE) provided primary energy levels and benchmarks for building renovation which may represent the cost-optimal and NZEB targets across Europe (Zangheri, 2018). In accordance with this study, the NZEB area appears characterised by medium-high and high recurrences of efficiency and RES technologies in all countries. For instance, a typical NZEB building has a well-insulated envelope (including insulation layers of 10-30 cm and double or triple low-e windows), efficient generators (e.g. condensing boiler or ground source heat pump or district heating) in some case assisted by heat recovery strategies, and renewable solar systems installed (normally both thermal and photovoltaic). On the other hand, the cost-optimal benchmarks would be more heterogonous. Various are the retrofit solutions able to reach this target, which overall is characterised by the competition between the deepest actions on the envelope, thermal systems and solar renewable systems. As expected, it is difficult to minimise the overall costs of applying a high-performance envelope, very efficient generators, a heat recovery strategy and a PV plant at the same time. This occurs only in some particular locations.

3.1 Methodology

In line with the EPBD recast, we decided to refer to the cost-optimal and NZEB renovation levels, taking into account mainly the references provided by Member States and the database collected for the ENTRANZE project about the investment costs for the renovation works and the energy consumptions before and after the refurbishment. Other European studies were consulted to support the development of the model, such as the results delivered by projects ODYSSEE[13] and ASSET[14].

Within the residential sector, we have distinguished between single-family houses (SFH) and multi-family houses (MFH), and because in several references the energy performances are normally expressed in terms of primary energy, we preferred to express the final regional energy saving potentials in terms of this energy level.

One may note that reference energy demands are normally available only at national level or for specific location selected as representative of the national average. To obtain regional values we applied a climatic factor, calculated as the ratio of the regional Heating Degree Days (HDD) and the national or local ones.

Figure 20 provides the scheme of calculation, including the input data and the indicators calculated for each region.

[13] https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

[14] https://asset-ec.eu/

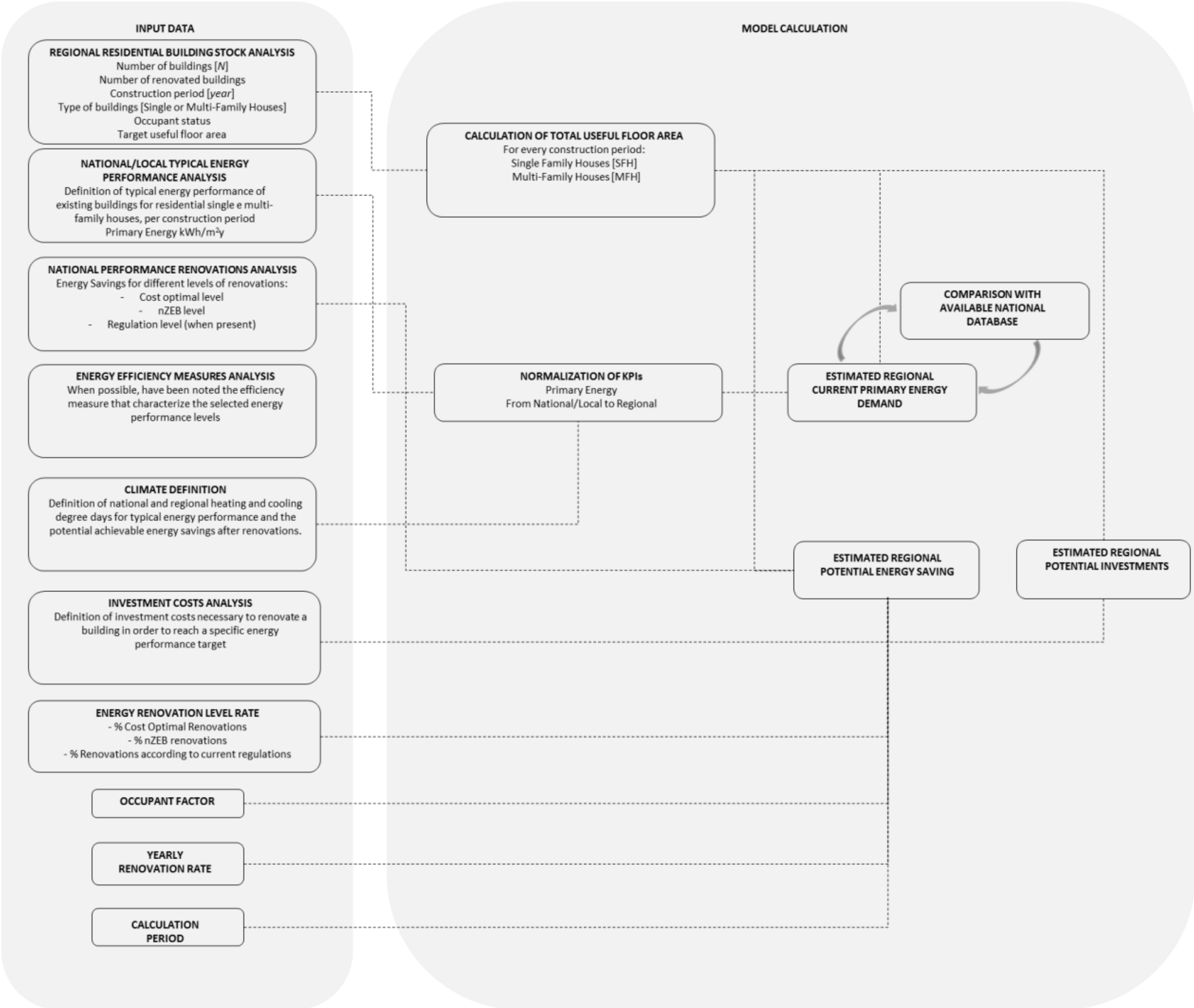

Figure 20. Calculation scheme.

Main calculation formulas

The Primary Energy Saving (PES) is calculated as the summation of the Primary Energy Saving for reference construction period (PESi):

$$PES = \sum_{i=before\ 1919}^{after\ 2000} PES_i$$

The reference construction periods are: before 1919; 1919-1960; 1961-1980; 1981-2000; after 2000, and PESi is obtained as:

$$PES_i = \sum_{k=SFH}^{MFH} PE_{ref,k,i} \times A_{k,i} \times f_{occ} \times R \times Y \times \left(f_{co} \times ES_{co} + f_{nZEB} \times ES_{nZEB}\right)$$

With:

- *k*: building type (SFH and MFH);
- $PE_{ref,k,i}$: reference primary energy demand of existing building type;
- $A_{k,i}$: total useful area over all building stock, for building type, for specific construction period (m²);
- f_{occ}: occupation factor (%);

– R: annual retrofit rate (%);

– Y: number of years of the calculation period;

– f_{co}: percentage of building retrofitted in compliance with cost optimal level (%);

– f_{NZEB}: percentage of building retrofitted in compliance with NZEB level (%)(f_{co}+f_{nZEB}=1);

– ES_{co}: cost-optimal energy saving respect to reference primary energy (%);

– ES_{nZEB}: nZEB energy saving respect to reference primary energy (%).

The total useful area $A_{k,i}$ is obtained as a function of the areas associated to different size categories (j: under 30 m^2, less than 40 m^2, less than 50 m^2, less than 60 m^2, less than 80 m^2, less than 100 m^2, less than 120 m^2, less than 150 m^2, 150 m^2 and over):

$$A_{k,i} = \sum_{j=under\ 30\ m2}^{over\ 150\ m2} N_{buildings,k,i} \times F_j \times S_j$$

Where $N_{buildings,k,I}$ is number of buildings, built in a specific construction period, for type of building; F_j is the percentage of building within a certain size category (%) and S_j is the target useful area for every size category.

Similarly the capitals associated to the renovation works (RC) are calculated as:

$$RC = \sum_{i=before\ 1919}^{after\ 2000} RC_i$$

Where RC_i is:

$$RC_i = \sum_{k=SFH}^{MFH} A_{k,ì} \times f_{occ} \times R \times Y \times \left(f_{co} \times IC_{co} + f_{nZEB} \times IC_{nZEB}\right)$$

With:

– k: building type (SFH and MFH);

– $A_{k,i}$: total useful area over all building stock, for building type, for specific construction period;

– f_{occ}: occupation factor;

– R: total annual retrofit rate (%);

– Y: number of years of the calculation period;

– f_{co}: percentage of building retrofitted in compliance with cost-optimal level (%);

– f_{nZEB}: percentage of building retrofitted in compliance with NZEB level (%);

– IC_{co}: investment costs for cost-optimal renovation (€/m^2);

– IC_{nZEB}: investment costs for nZEB renovation (€/m^2).

Data sources and assumptions

The main data sources used for this study are summarised in the table below (Table 1).

Table 1. Main data sources considered for the estimation of regional energy saving potential.

Input data	Source	Level
Number of dwellings per construction period Number of dwellings per type of building Useful area per type of building Status of occupation	• ESTAT Census Hub • ODYSSEE	NUTS2 National
Primary energy consumptions of typical building types Primary energy levels associated to cost-optimal renovations Primary energy levels associated to NZEB renovations	• Cost-Optimal Reports • ENTRANZE Database • NZEB definitions declared by Member States	National (and/or Local)
Investment costs associated to cost-optimal renovations Investment costs associated to NZEB renovations	• Cost-Optimal Reports • ENTRANZE Database	National
Heating Degree Days (HDD)	• PVGIS	Local
Residential energy consumptions	• EUROSTAT	National

The key indicators characterising the regional building stocks were extracted from the Census Hub[15] of EUROSTAT, based on the 2011 Census national databases. In order to take into account the recent variations on the building stocks, like the new constructions and the demolition of older buildings over the period 2011-2016, we referred to the ODYSSEE database[16]. To downscale this data from national to NUTS2 level, we applied a proportion based on the number of existing buildings in 2011.

The energy and cost reference values were derived or assumed from the Member States' cost-optimal reports and/or the ENTRANZE Database. Referring to the countries of the 228 regions object of study, on one hand the second round of cost-optimal reports (prepared in 2018) were available for all Member States except Croatia, Malta and Portugal. On the other, the ENTRANZE project covered Austria, the Czech Republic, Finland, France, Germany, Italy, Romania and Spain. For the uncovered countries, some assumptions were made taking into account similarities with other Member States. Further, additional similar assumptions were made for countries where the information required for the model after the consultation of the available sources was incomplete or missing, in particular: Malta, Portugal, the Netherlands, Sweden, Bulgaria, Croatia, Estonia, Poland and Slovakia.

In order to base our analysis on reliable input data, we considered more than one source and we applied some correction techniques. For the primary energy consumptions of reference existing buildings (before any renovation work) we used as main reference sources the values derived from the National Cost-Optimal report and from the ENTRANZE calculations, following a bottom-up approach. Then we corrected them taking into account the total consumptions of the residential sector (from EUROSTAT), and checked the values obtained against those collected in the ODYSSEE database. In Table 2, for each Member State we report the main reference source, a qualitative indication of the weight of the calibration that has been applied to match the energy consumptions of the national residential sector (from ESTAT) and two comparisons with the ESTAT (at building stock level) and ODYSSEE (at building level) datasets. With regards to the first comparison with the total residential consumptions, the percentage is always below 100% because our calculation does not take into account the energy consumed by domestic appliances, which are not subject to improving measures.

[15] https://ec.europa.eu/eurostat/web/population-and-housing-census/census-data/2011-census
[16] https://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

Table 2. Primary Energy (PE) demand of reference existing buildings: references and comparison with national data sources.

MS	Main reference source	Calibration applied based on ESTAT data	Modelled vs. ESTAT PE consumptions of existing building stock	Modelled vs. ODYSSEE PE consumptions of existing average building type
AT	ENTRANZE	high	85%	similar
BE	National Cost-Optimal report	medium	79%	similar
BG	Assumed from similar MS	none	72%	similar
HR	Assumed from similar MS	none	69%	similar
CY	National Cost-Optimal report	medium	78%	higher
CZ	ENTRANZE	medium	90%	similar
DK	National Cost-Optimal report	none	70%	similar
EE	National Cost-Optimal report	high	68%	lower
FI	ENTRANZE	high	65%	similar
FR	ENTRANZE	low	83%	similar
DE	ENTRANZE	medium	86%	similar
EL	National Cost-Optimal report	none	68%	similar
HU	National Cost-Optimal report	none	88%	similar
IE	National Cost-Optimal report	high	68%	slightly higher
IT	ENTRANZE	none	87%	similar
LV	National Cost-Optimal report	medium	74%	lower
LT	National Cost-Optimal report	medium	71%	similar
LU	National Cost-Optimal report	low	66%	similar
MT	Assumed from similar MS	medium	74%	higher
NL	Assumed from similar MS	medium	90%	slightly higher
PL	National Cost-Optimal report	high	71%	similar
PT	Assumed from similar MS	none	69%	slightly higher
RO	ENTRANZE	high	86%	lower
SK	National Cost-Optimal report	low	86%	similar
SI	National Cost-Optimal report	none	71%	similar
ES	ENTRANZE	medium	76%	similar
SE	Assumed from similar MS	medium	74%	slightly higher

The source references used for the definition of energy levels associated to the cost-optimal and NZEB renovations are shown in Table 3. As for NZEB, we referred to the definition of existing buildings where available, otherwise to that of new buildings. Since the reference sources normally provide values at national level, we applied a climatic factor based on the ratio between regional and national HDD values. Also in this case we referred to Typical Meteorological Years (TMY) provided by the Photovoltaic Geographical Information System (PVGIS) of the JRC (see Chapter 2.1).

Table 3. References used for Cost-Optimal and NZEB renovation levels.

MS	Main reference source for Cost-optimal level	Main reference source for NZEB level
AT	ENTRANZE	Official definition (existing)
BE	National Cost-Optimal report	Official definition (existing)
BG	Assumed from similar MS	Official definition (existing)
HR	Assumed from similar MS	Official definition (existing)
CY	National Cost-Optimal report	Official definition (existing)
CZ	ENTRANZE	Official definition (new)
DK	National Cost-Optimal report	Official definition (new)
EE	National Cost-Optimal report	Official definition (new)
FI	ENTRANZE	Official definition (existing)
FR	ENTRANZE	Official definition (existing)
DE	ENTRANZE	Official definition (existing)
EL	National Cost-Optimal report	Official definition (existing)
HU	National Cost-Optimal report	Official definition (existing)
IE	National Cost-Optimal report	Official definition (new)
IT	ENTRANZE	Official definition (new)

LV	National Cost-Optimal report	Official definition (existing)
LT	National Cost-Optimal report	Official definition (existing)
LU	National Cost-Optimal report	Official definition (existing)
MT	Assumed from similar MS	Official definition (existing)
NL	National Cost-Optimal report	Official definition (new)
PL	National Cost-Optimal report	Official definition (existing)
PT	Assumed from similar MS	Official definition (existing)
RO	ENTRANZE	Official definition (existing)
SK	National Cost-Optimal report	Official definition (existing)
SI	National Cost-Optimal report	Official definition (existing)
ES	ENTRANZE	Official definition (new)
SE	Assumed from similar MS	Official definition (new)

With regards to investments costs (Table 4), which are usually difficult to obtain, we started from the same reference sources and applied a calibration based on the data collected by the ASSET project[17] (also used for the PRIMES model) and the performance discharge between the reference point and the official NZEB definition. After the consolidation of national values, we applied a weighting factor to consider the economic differences between regions in each country. This weighting factor has been defined on the basis of the regional compensation of employees, as provided by the EUROSTAT database[18].

Table 4. Renovation costs: references and calibrations.

MS	Main reference source	Calibration for Cost-Optimal, based on PRIMES dataset	Calibration for NZEB based on official definition
AT	ENTRANZE	low	medium
BE	National Cost-Optimal report	medium	none
BG	Assumed from similar MS	none	medium
HR	Assumed from similar MS	none	low
CY	National Cost-Optimal report	low	medium
CZ	ENTRANZE	low	low
DK	National Cost-Optimal report	medium	medium
EE	Assumed from similar MS	low	low
FI	ENTRANZE	low	low
FR	ENTRANZE	low	low
DE	ENTRANZE	low	low
EL	National Cost-Optimal report	low	high
HU	National Cost-Optimal report	medium	low
IE	National Cost-Optimal report	high	none
IT	ENTRANZE	none	low
LV	National Cost-Optimal report	low	low
LT	National Cost-Optimal report	low	medium
LU	National Cost-Optimal report	low	medium
MT	Assumed from similar MS	none	medium
NL	Assumed from similar MS	medium	low
PL	Assumed from similar MS	low	low
PT	Assumed from similar MS	none	high
RO	ENTRANZE	none	low
SK	Assumed from similar MS	low	low
SI	National Cost-Optimal report	none	medium
ES	ENTRANZE	none	low
SE	Assumed from similar MS	low	low

An estimation of the employment effects associated to the deployment of building renovation was derived on a yearly base. To do that, we disaggregated the investment costs (i.e. CAPEX) between "equipment" (including the building components, systems and construction materials) and "construction" (i.e. the workforce of the construction companies and installation jobs). The business profit of 10%, the overhead rate of 15% and the

[17] https://ec.europa.eu/energy/sites/ener/files/documents/2018_06_27_technology_pathways_-_finalreportmain2.pdf
[18] https://ec.europa.eu/eurostat/web/products-datasets/product?code=nama_10r_2coe

VAT rate (applied by each Member State for the renovation of private dwellings[19]) were deduced from the total investment cost, which was then divided by the average national labour cost for these work areas, as estimated in the Euro Observer methodology report[20]. It was assumed that the labour in the construction sector can be mainly covered by the regional and national workforce, while jobs related to equipment affect a wider area (continental, at least). Thus, for this sector, we used an EU weighted average of labour cost (53000 €/FTE), based on the current production of insulation materials, windows and heating/cooling systems within Europe.

Input data

Based on the sources, assumptions and methods described above, the figures below show the main input data used for this study. They take into consideration the energy demand of existing buildings, as well as the energy saving, and investment costs associated to the cost optimal and NZEB renovations. The data included in Annex 1 can be used as key operational characteristics of the technical renovation solutions reaching the cost optimal and NZEB energy levels.

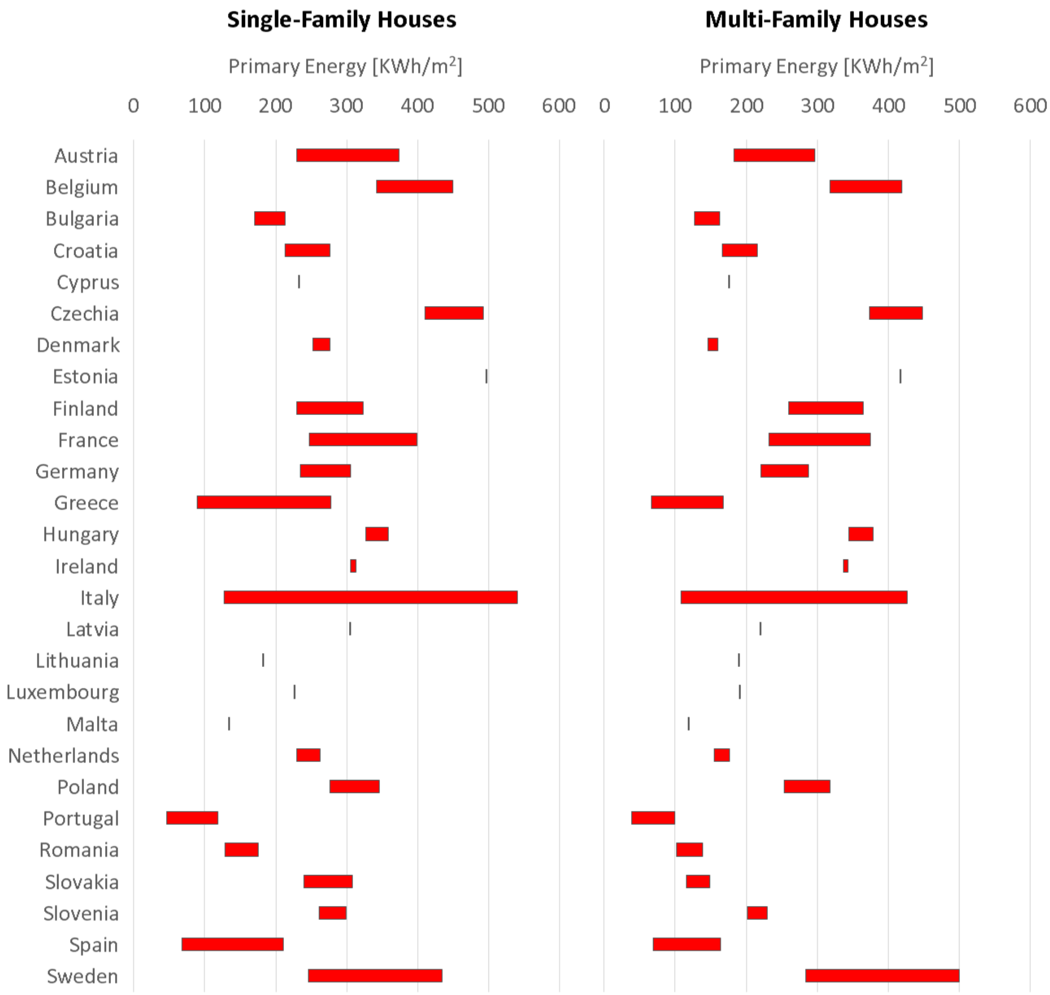

Figure 21. Reference range of primary energy demand of existing buildings (built before 1980).

[19] https://ec.europa.eu/taxation_customs/sites/taxation/files/resources/documents/taxation/vat/how_vat_works/rates/vat_rates_en.pdf
[20] https://publications.ecn.nl/ECN-E--17-076

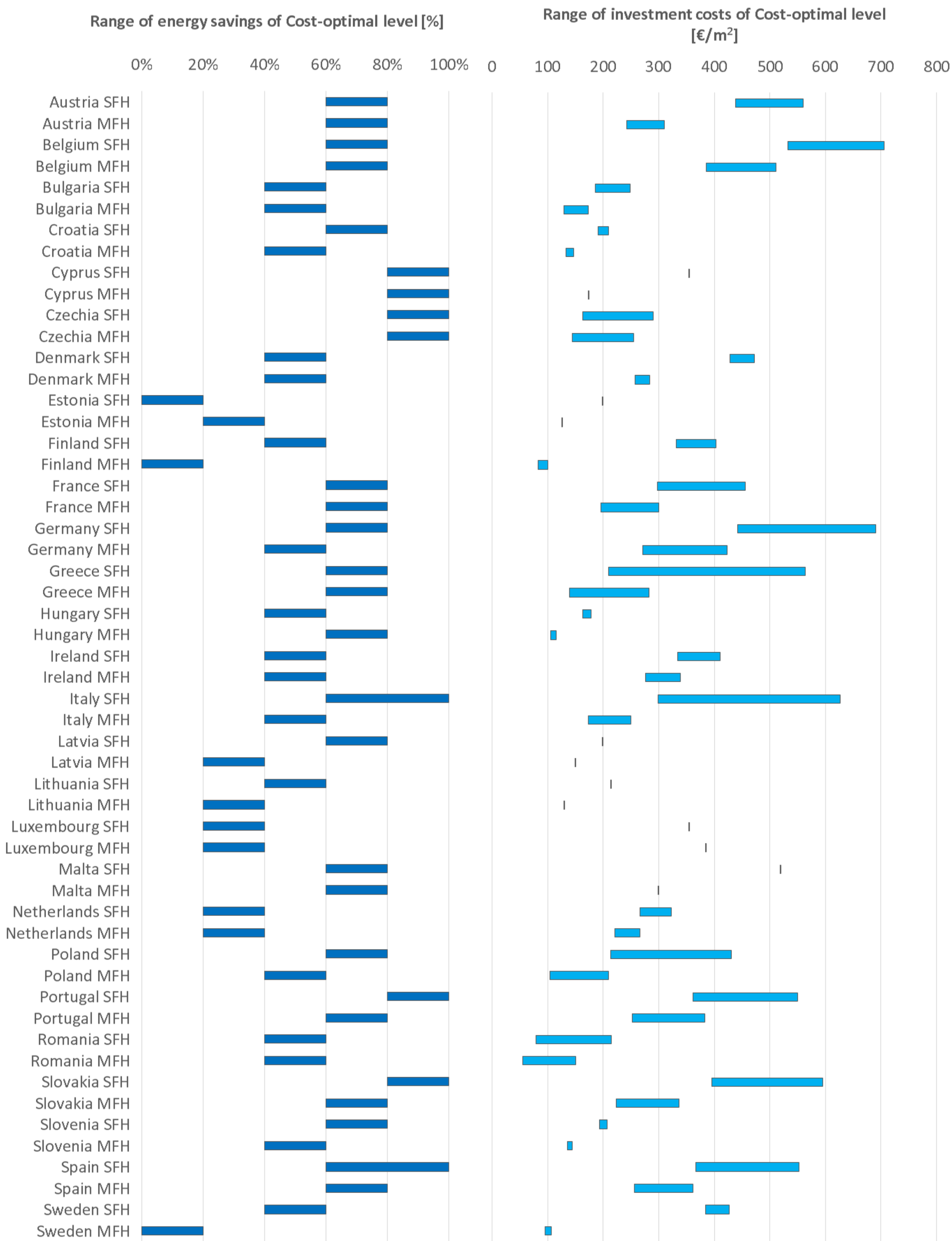

Figure 22. Ranges of energy savings and investment costs associated to the cost-optimal renovation level for Single-Family (SFH) and Multi-Family (MFH) houses.

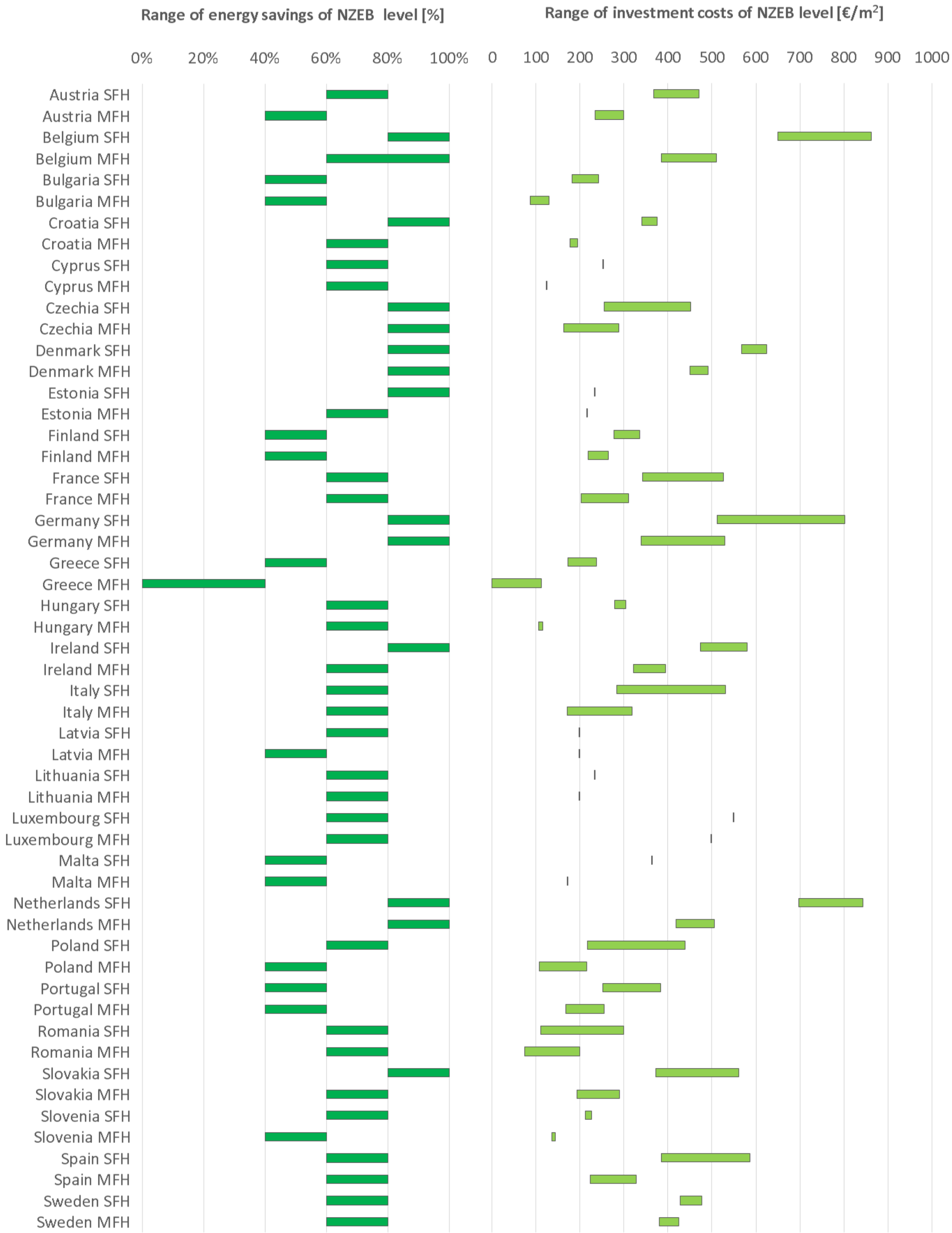

Figure 23. Ranges of energy savings and investment costs associated to the NZEB renovation level for Single-Family (SFH) and Multi-Family (MFH) houses.

3.2 Results and discussion

We applied our model to the existing residential stock, to estimate the total technical potential based on the cost-optimal and NZEB levels at regional level, as well as to evaluate the impact of different development scenarios of renovation rate by 2050.

Regional technical potential

In order to estimate the maximum technical potential at regional level, we decided to select the lower energy value between the NZEB and cost-optimal levels. In particular, we considered:

- the NZEB level for Belgium, Croatia, the Czech Republic, Denmark, Estonia, France, Germany, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, the Netherlands, Poland, Romania, Slovenia and Sweden.
- The cost-optimal level for Austria, Bulgaria, Cyprus, Finland, Greece, Malta, Portugal, Slovakia and Spain.

As shown in Table 5 the main negative discrepancies between these potentials are observed in Greece, Portugal and Malta. In these cases, the official NZEB definition is probably less ambitious than elsewhere. On the contrary, the NZEB definitions of the Netherlands, Estonia and Denmark appear extremely ambitious. However, it should be noted that these definitions refer to new buildings (Table 3), since these Member States did not provide specific references for existing buildings.

Table 5. Primary energy saving potential at national level associated to the cost-optimal and NZEB renovation options.

MS	Cost-optimal potential [TWh]	NZEB potential [TWh]	% Difference (NZEB - Cost-optimal)
AT	48	39	-20%
BE	49	75	54%
BG	20	19	-7%
HR	14	18	30%
CY	3	2	-16%
CZ	92	99	8%
DK	18	35	95%
EE	5	11	112%
FI	21	25	16%
FR	364	407	12%
DE	446	580	30%
EL	32	18	-45%
HU	49	52	5%
IE	13	18	41%
IT	265	282	6%
LV	5	7	35%
LT	7	9	35%
LU	1	3	94%
MT	1	0	-31%
NL	44	109	150%
PL	122	128	5%
PT	22	13	-43%
RO	60	73	22%
SK	26	24	-6%
SI	8	8	5%
ES	137	129	-5%
SE	49	68	39%

As for the absolute value of the regional technical potential Figure 24, which is strongly related to the absolute number of existing dwellings, we observe a high variance also within the national boundaries. The greater energy savings are associated to the most populated regions (in Germany, France, Italy and Spain), but some areas in eastern Europe (Poland, the Czech Republic, Romania) also stand out for significance.

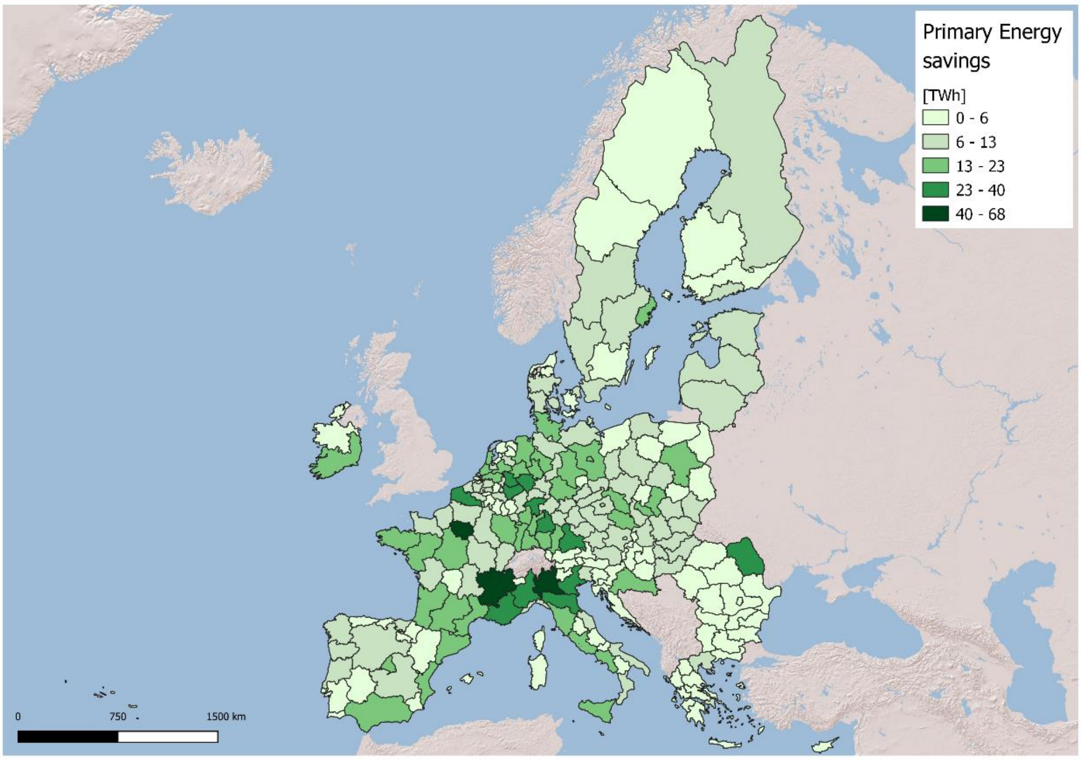

Figure 24. Absolute technical potential, in terms of primary energy savings, associated to the lower energy level (between NZEB and Cost-optimal) identified for each NUTS2 region.

More homogeneous at Member State level is the overall picture if we look at the percentage of saving rate (Figure 25). It mainly depends on the ambition of either the NZEB definition or cost-optimal level, since for each Member State we consider the lower value between these two references. Small differences between regions of the same countries are due to the adjustment of the energy target as a function of climatic conditions. Here the higher percentages are associated to the Czech Republic, Slovakia, the Netherlands, Belgium, Portugal and Denmark.

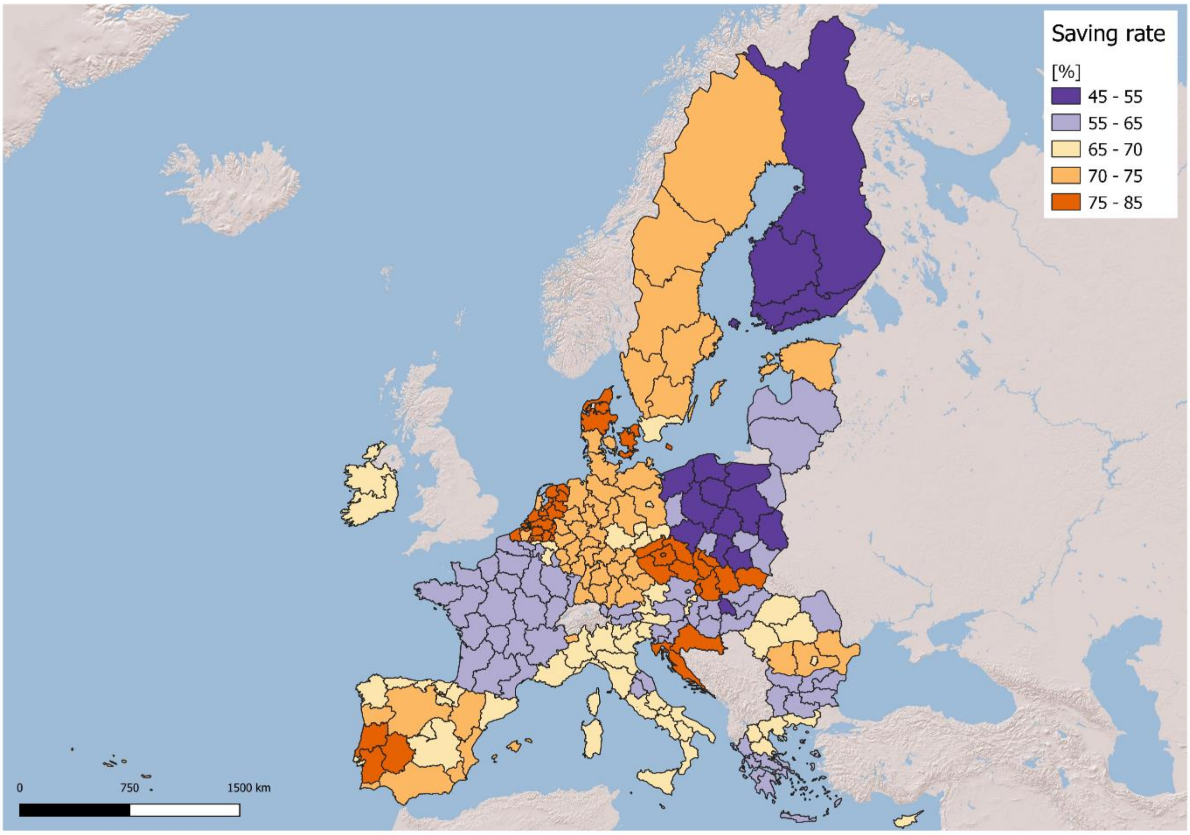

Figure 25. Percentage of energy saving, with respect to current consumptions, associated to the lower energy level (between NZEB and Cost-optimal) identified for each NUTS2 region.

The maps on the total investments (Figure 26) and the associated impact on occupation (Figure 27) make the most populous areas stand out again, such as the regions of Paris, Milan, Barcelona and Munich.

In general, Slovakia, Poland, Finland and partially Bulgaria showed the lowest rates of energy saving with values ranging from 45 to 55%. More specifically the region with the highest saving rate is Východné Slovensko (SK04) with 85% of saving rate, followed by Moravskoslezsko (CZ08) and Stredné Slovensko (SK03) with 84%.

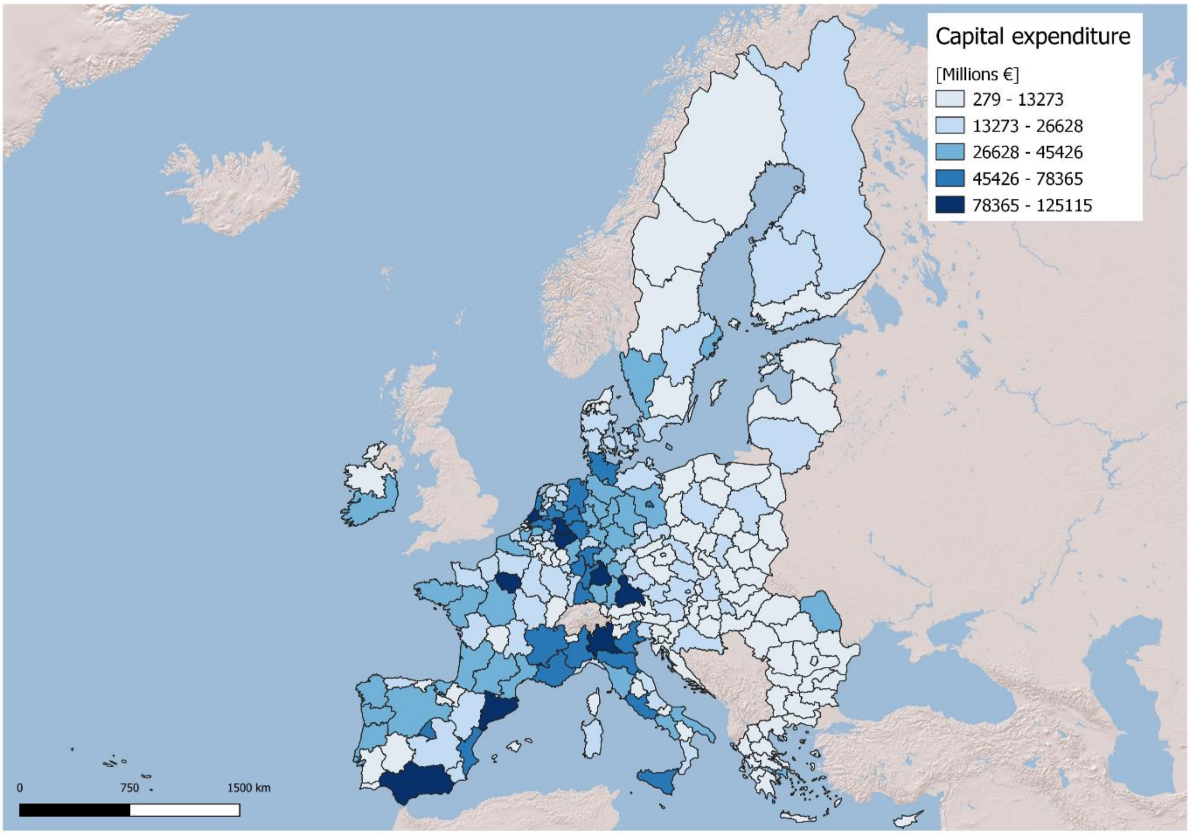

Figure 26. Absolute amount of investment costs associated to the renovation (to the lower energy level between NZEB and Cost-optimal) of the regional building stocks.

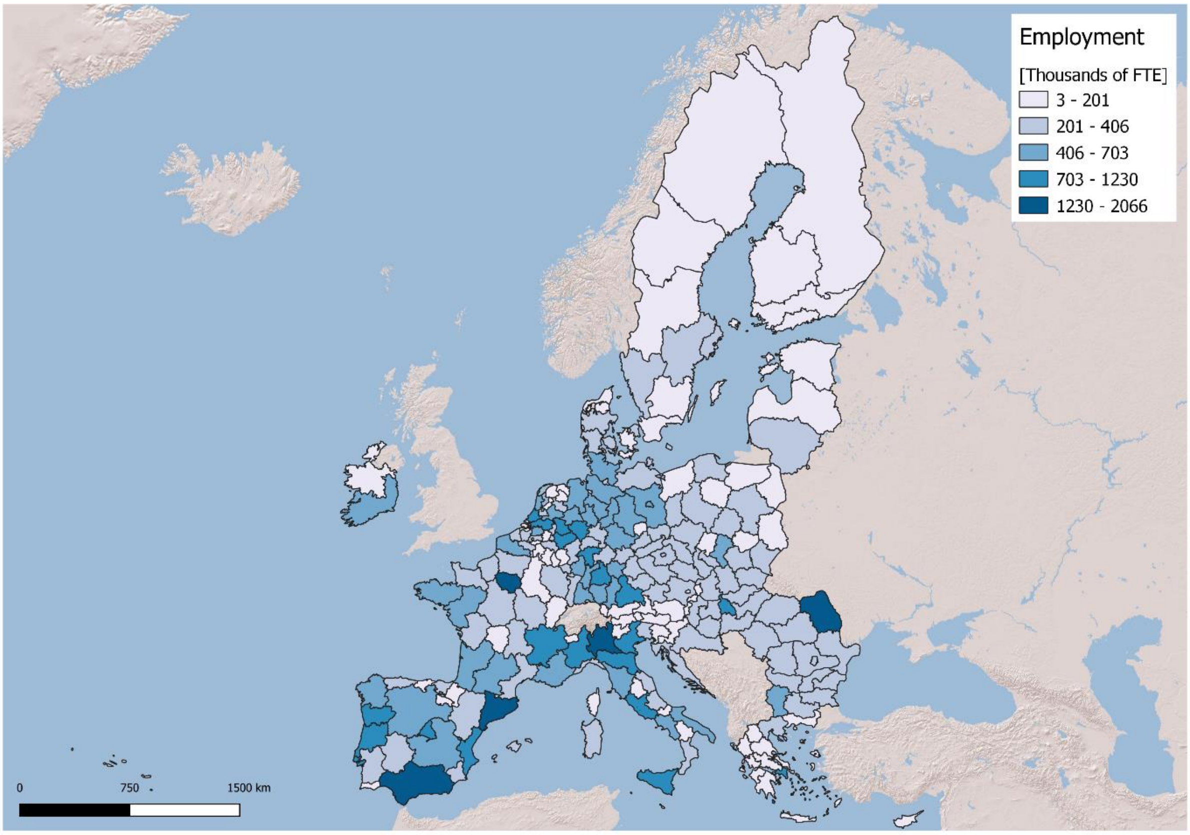

Figure 27. Absolute value of Full-Time Equivalent (FTE) job positions associated with the total investment costs.

The job positions associated with the total investment costs showed heterogeneity across the European regions, with low values in Austria, Cyprus, Greece, Ireland (Midland and Western), and Sweden. Only six regions (RO21, ITC4, ES61, FR10, ES51, DEA1) from the 235 (2.5%) showed high values exceeding 1230 FTE.

It is also interesting to observe how the ratio between energy benefit and economic expenditure (as a kind of efficiency) changes among the European regions, as shown in Figure 28.

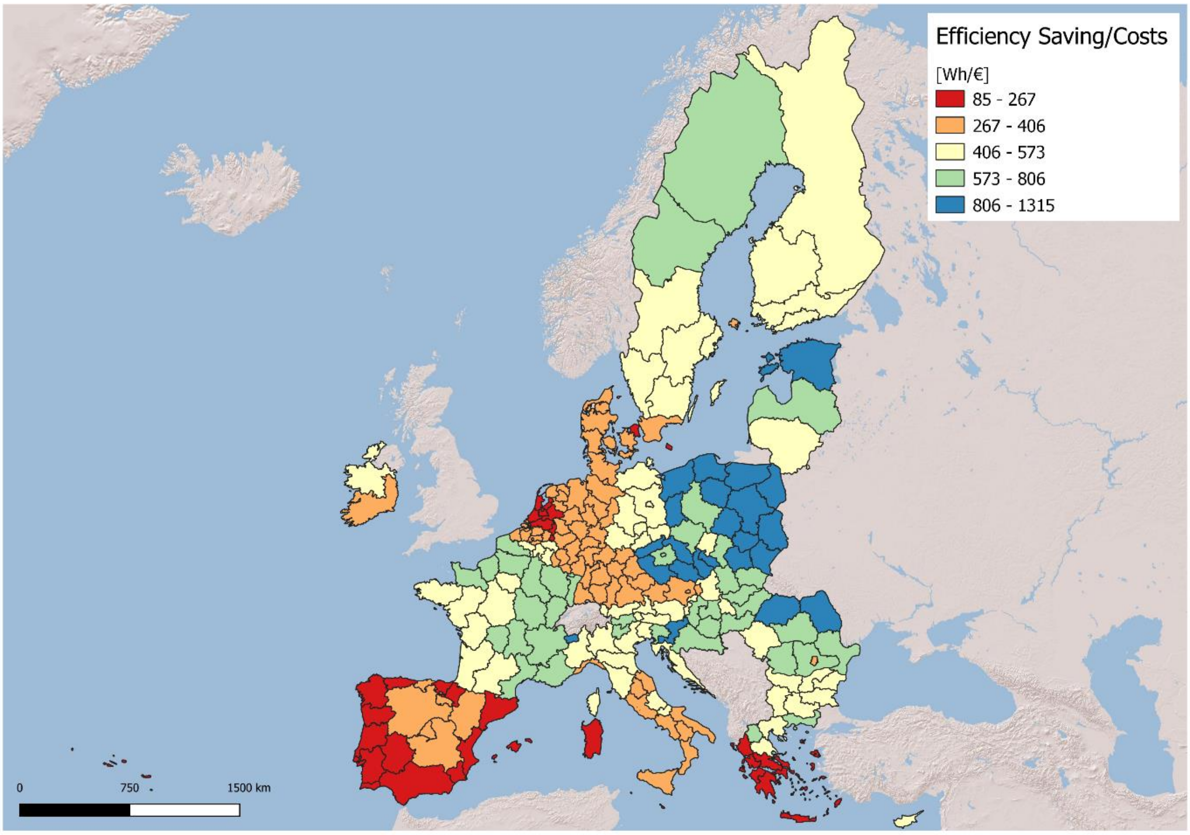

Figure 28. Ratio between energy savings and economic expenditure.

The countries with the lowest efficiency saving/cost values are Portugal, Spain, the Netherlands, Greece and two Danish regions. The highest efficiency saving/costs values were observed in eastern Europe and specifically in Poland, the Czech Republic and two regions in Romania (RO11 and RO12). The majority of German regions showed lower values than in France, Sweden, Balkans and the North of Italy, with the exemption of some eastern German regions.

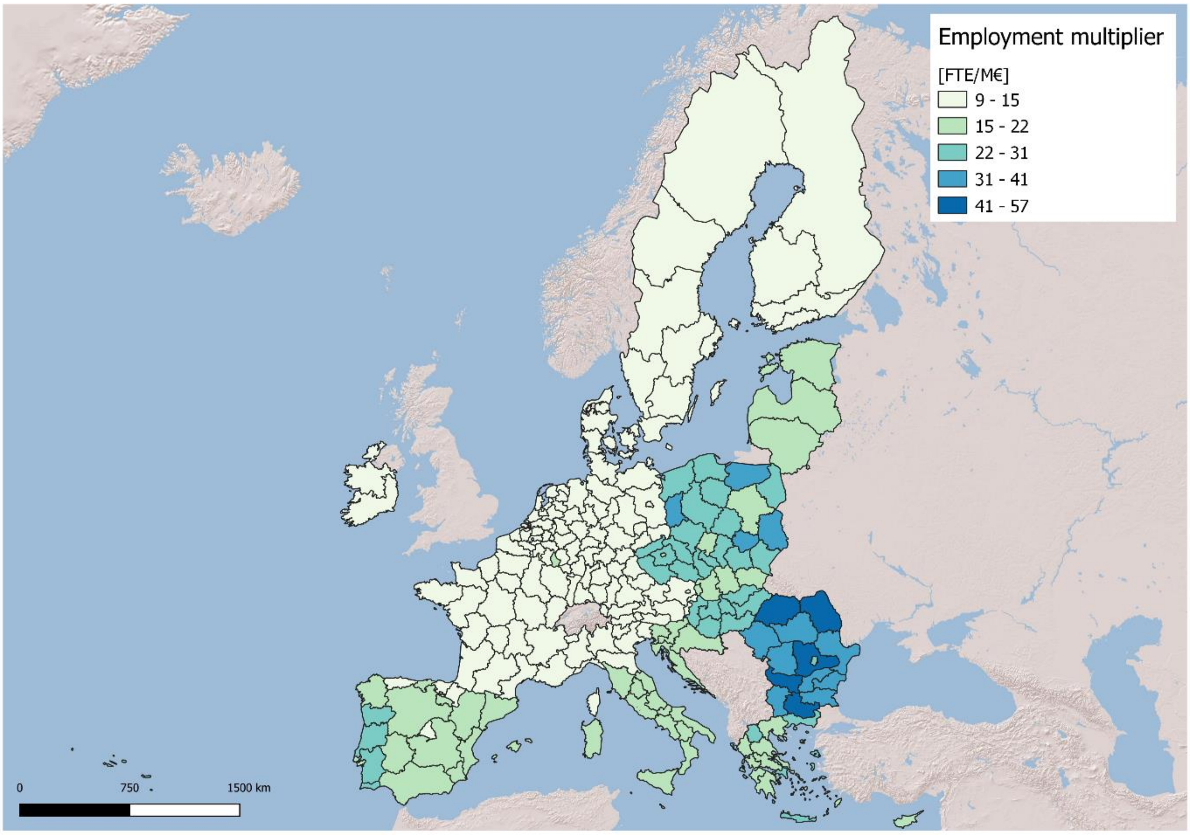

Figure 29. Employment multiplier associated to the investment of 1 Million of euro.

As it can be observed in Figure 30, the value of the employment multiplier for the majority of the regions ranged from 9-15 FTM/M€ especially in north, west and central Europe. Higher variability was evident in the eastern countries with the highest values recorded in Romanian regions. The southern countries showed a more homogeneous pattern with values ranging from 15-22 with the exception of Portugal (P11 and P16).

The values of energy savings potential and associated capital expenditure calculated for all EU regions are provided in Annex 2.

Development over the period 2021-2050

As discussed above, the capability to achieve the technical potential depends on how and when the renovation rates will be developed in the future. Different scenarios can be made, such as these ones:

- Scenario 0: yearly 1% of the dwellings are renovated up to the cost-optimal level. This implies the energy renovation of 30% of homes by 2050.
- Scenario 1: the renovation rate is gradually increased to 2% in 12 years and maintained thereafter. This implies an average renovation rate (r) of 1.8% and the renovation (at the cost-optimal level) of 54% of existing homes by 2050.
- Scenario 2: the renovation rate is gradually increased to 3% in 10 years and maintained thereafter. This translates into an average renovation rate (r) of 2.6% and the renovation (at the cost-optimal level) of 79% of existing homes by 2050.

It can be noticed that we always refer to cost-optimal level. This is because we believe that it is a more appropriate reference for studying the dynamics that affect existing buildings. In fact, policy measures aimed to increase renovation rates can easily refer to the intrinsic meaning of cost-optimality, which maximises the economic benefit of the building owner.

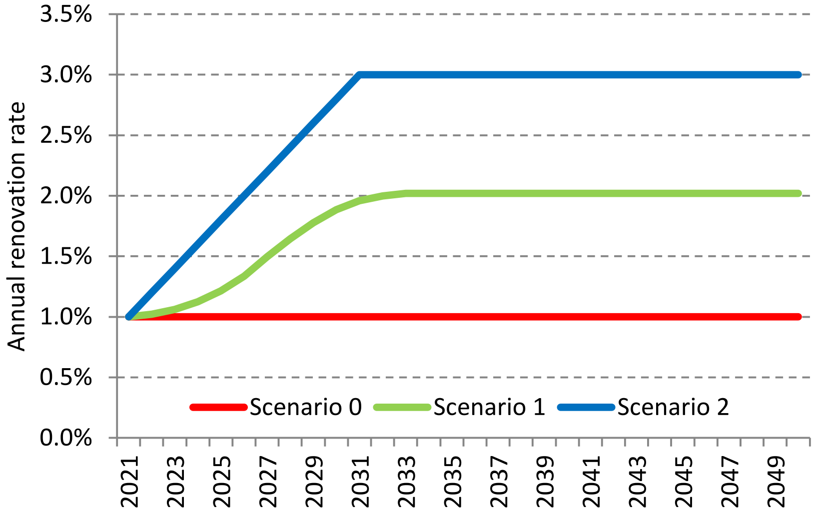

Figure 30. Development of yearly renovation rate over the period 2021-2050, under 3 scenarios.

At European level, the impacts shown in Figure 31 can be derived. We estimate that 66% of the technical potential would be achieved following the trajectory of Scenario 2. The energy ammount of 1517 TWh represents 40% of the current residential (primary) energy consumptions, and almost 10% of the total primary energy consumptions (of EU27 in 2018). For the associated impact on employment, we obtained the cumulated value of approximately 55 millions of Full Time Equivalent job places. The annual average of 1.83 millions of FTE represents 20% of the current employees in the construction sector.

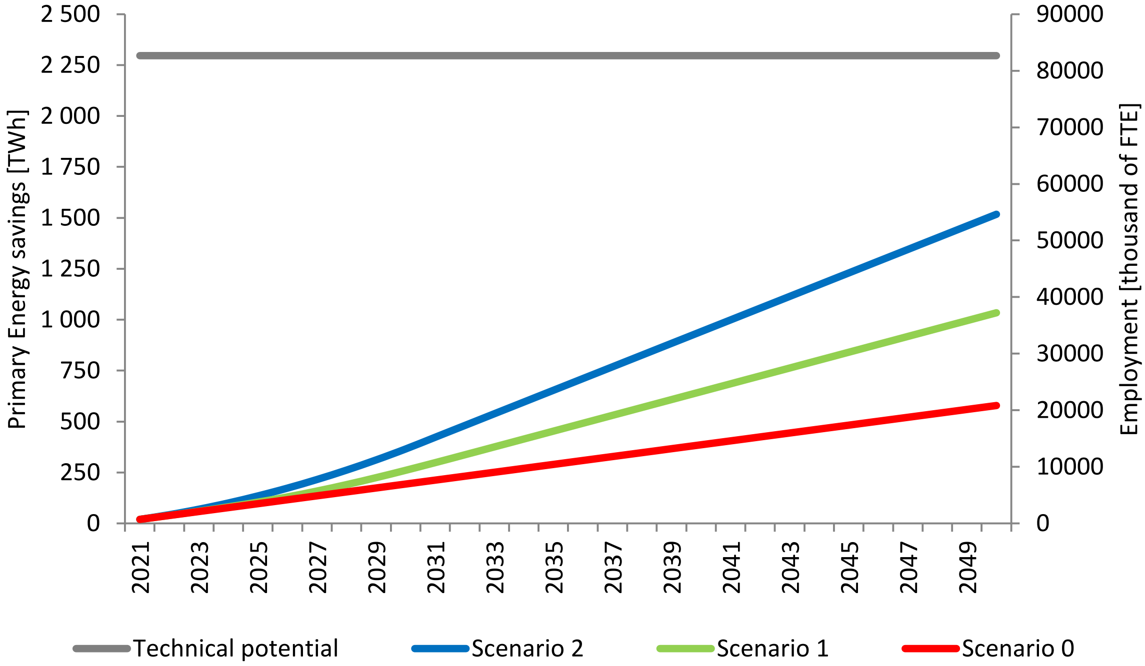

Figure 31. Energy and employment development at EU27 level under the scenarios analysed.

Table 6 provides the energy and economic benefits at national level under the hypothesis of Scenario 2.

Table 6. Benefits at national level under Scenario2.

MS	Primary energy savings [TWh]	Capital expenditure [M€]	Employment [thousand of FTE]
AT	38.3	90172	1003
BE	38.4	122096	1439
BG	16.2	33472	1338
HR	11.1	14237	289
CY	2.2	4340	94
CZ	72.6	59753	1450
DK	14.0	54087	501
EE	4.1	4978	77
FI	16.7	38515	376
FR	287.8	481005	6117
DE	352.0	1090226	12886
GR	25.6	88898	1902
HU	38.9	32557	947
IE	10.3	24906	335
IT	209.5	525320	7837
LV	4.2	6428	113
LT	5.2	11509	202
LU	1.0	4877	73
MT	0.6	3076	59
NL	34.6	140078	1557
PL	96.1	112611	3066
PT	17.5	110021	2515
RO	47.2	52170	2372
SK	20.4	38345	739
SI	6.0	7107	135
ES	107.8	449625	7005
SE	35.7	88581	854
EU27	1514	3688988	55279

4 Further options to generate data at local level

In the context delineated in the previous chapters, new collections of harmonised data describing the conditions at regional and local level will be particularly useful. To generate them, different approaches can be considered, within two main categories: bottom-up and top-down methods. In the following sections we discuss and provide exemplary applications of a bottom-up approach based on data at building level collected under the INSPIRE framework, and a top-down technique, downscaling national data to local level.

4.1 Bottom-up approach

Under the framework of the INSPIRE Directive new building datasets are becoming available.

The INSPIRE Directive aims to create a European Union Spatial Data Infrastructure for the purposes of EU environmental policies and policies or activities which may have an impact on the environment. This European Spatial Data Infrastructure will enable the sharing of environmental spatial information among public sector organisations, facilitate public access to spatial information across Europe and assist in policy-making across boundaries. INSPIRE is based on the infrastructures for spatial information established and operated by the Member States of the European Union and addresses 34 spatial data themes, one of them being Buildings (Martirano, 2016).

The Directive came into force on 15 May 2007 and is being implemented in various stages, with full implementation required by 2021. According to the INSPIRE roadmap, by 21 October 2020, Member States shall make discoverable (in the INSPIRE Geoportal) and downloadable, even though possible use and access restrictions may apply, their harmonised buildings datasets, conformant to a common core data model.

This INSPIRE core data model includes, among others, a set of attributes that are potentially relevant to the overall purpose of this report (besides the building geometry, which can be 2D or 3D):

- conditionOfConstruction (functional, under construction, etc.)
- dateOfConstruction/dateOfRenovation
- currentUse (according to a predefined list of values)
- numberOfDwellings
- numberOfBuildingUnits
- numberOfFloorsAboveGround

Most of these attributes are optional, however when they are mandatory and their values are unavailable, a reason for not providing their value is allowed (e.g. “unknown” or “unpopulated”). Therefore, it may happen that a building dataset contains only the building geometries.

Conversely, there can be buildings datasets containing more attributes (with a meaningful value) than those present in the INSPIRE core data model, conformant to national or local data models which extend the INSPIRE core data model, providing a richer semantic content.

Even if the deadline to provide INSPIRE harmonised buildings datasets is at the end of October 2020, many buildings datasets (independently from their level of harmonisation and conformance to the INSPIRE core data model) are already discoverable in the INSPIRE Geoportal.

In this context, it is interesting to explore how this information (at building level) can be used to generate new statistics at local and regional level. As an example, a comparison between statistics at NUTS-3 level obtained from Census Hub data and from INSPIRE data is presented.

The test area selected is the NUTS-3 province of Madrid in Spain. The selected country is Spain, because at the moment it is the only one for which semantically rich INSPIRE buildings data are available, and even though they are not yet discoverable in the INSPIRE geoportal, they are downloadable from the national cadastre website[21]. This buildings data are conformant to a national data model which extends the INSPIRE core data model, containing additional attributes such as the officialArea, which can correspond to the gross floor area or to other definitions whose reference has to be provided.

Two comparisons have been made:

[21] http://www.catastro.minhap.es/webinspire/index.html

- related to the typology of residential buildings (1-dwelling buildings, 2-dwellings buildings, 3 or more dwellings buildings),
- related to the period of construction.

In order to make the comparison with the Census Hub data previously downloaded, 181 gml files containing INSPIRE buildings datasets for the 181 municipalities of the province of Madrid have been downloaded, ingested into a PostGIS database and then filtered according to the following rule:

conditionOfConstruction='functional' and currentUse='1_residential'

Then, a categorisation according to the child values of the parent value '1_residential' of the currentUse attribute has been made.

The comparison with the Census Hub data is shown in Figure 32.

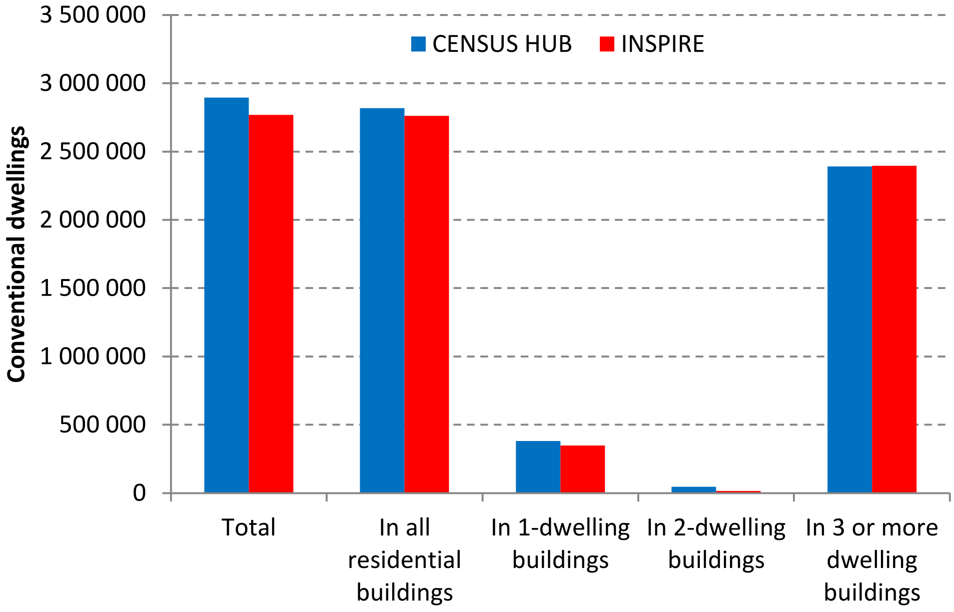

Figure 32. Comparison between Census Hub data and INSPIRE data related to residential buildings typologies.

Regarding the comparison related to the period of construction, the same filter used for the previous comparison has been applied to the INSPIRE data and then a categorisation according to the periods of construction of the Census Hub data has been made.

The comparison is shown in Figure 33.

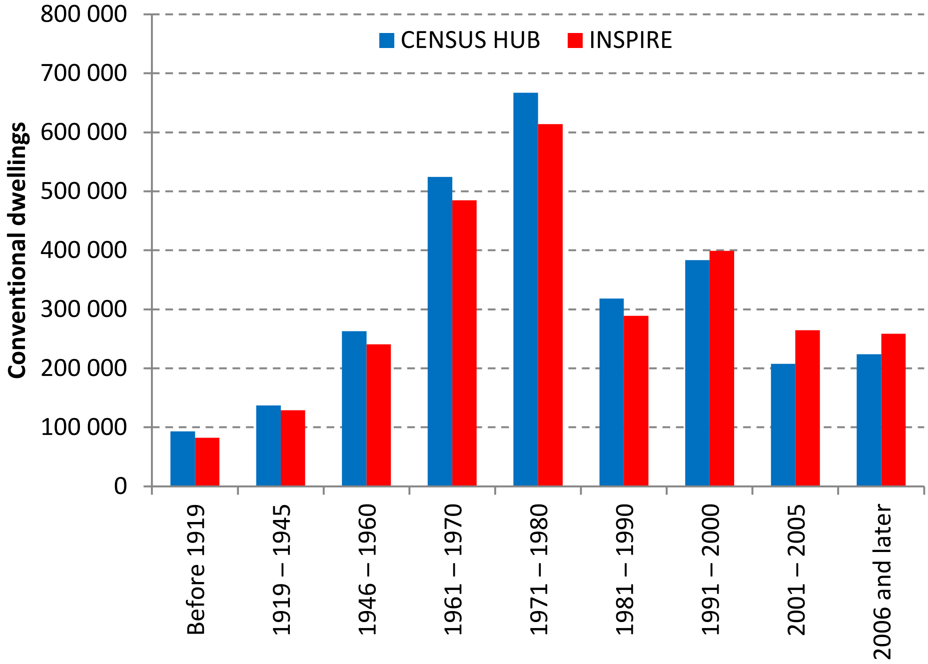

Figure 33. Comparison between Census Hub data and INSPIRE data related to periods of construction.

Despite some deviation, more evident for some categories, the agreement between the two sources is good. The assessment of the reliability of the two sources requires deeper investigations into the collection and processing of the source data.

Apart from the possibility to generate statistics at local and regional level (aggregating at higher level data available at building level), the INSPIRE data at building level offers a wide range of uses.

An example is represented by Governments who want to revamp their white certificates scheme, focusing on the renovation of older and larger residential and office buildings through standardised measures. In this case, some preliminary analyses of the building stock may provide better insights. For example, the two following indicators can be easily generated by applying the following filters:

1) conditionOfConstruction = 'functional' and currentUse = '1_residential' and numberOfDwellings >100 and dateOfConstruction before (or equal to) 1990.
2) conditionOfConstruction = 'functional' and currentUse = '4_1_office' and dateOfConstruction before (or equal to) 1990 and officilArea_value >= 250 m^2

The location of the buildings belonging to the two indicators are shown on the left-hand side of Figure 34 and Figure 35 respectively, whilst to the right is a classification of the 181 municipalities of the province of Madrid in terms of number of buildings belonging to the two indicators.

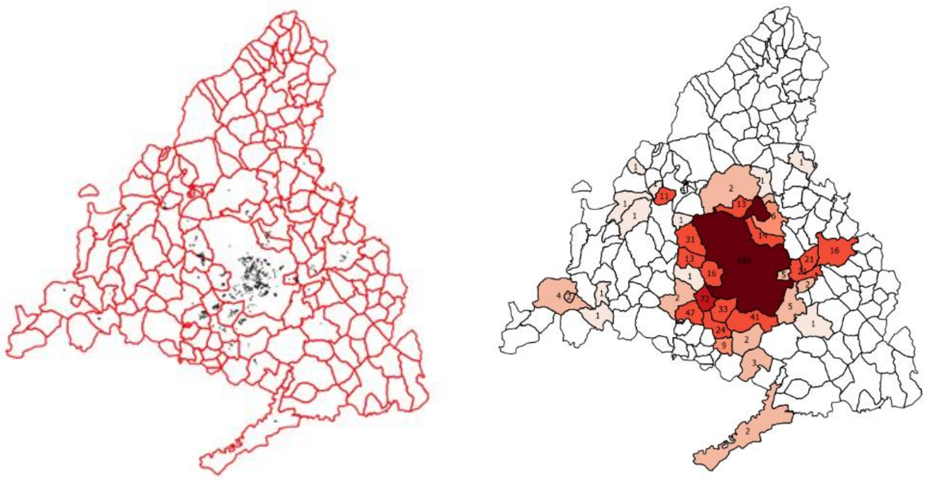

Figure 34. Location of the 1.108 buildings belonging to the indicator I1 (left) and classification of the 181 municipalities in terms of number of buildings belonging to the indicator I1 (right).

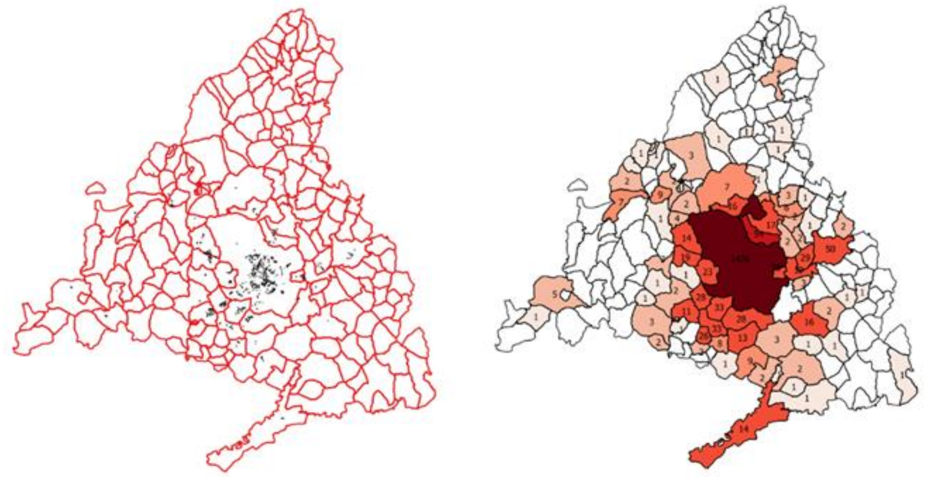

Figure 35. Location of the 2.083 buildings belonging to the indicator I2 (left) and classification of the 181 municipalities in terms of number of buildings belonging to the indicator I2 (right).

The availability of georeferenced data at building level offers many other possibilities of use, for example combining/matching other (social, climatic, economic) indicators or executing (even complex) spatial analyses with other georeferenced data such us utility networks and transport networks.

In order to do these analyses for all EU countries, INSPIRE harmonised buildings data should be available for each country.

At the time of writing this report, there are 1.651 buildings datasets discoverable in the INSPIRE Geoportal, of which 170 are downloadable. Considering only the national spatial coverage of the datasets, the number of buildings datasets discoverable in the INSPIRE Geoportal drops from 1.651 to 70, of which only 27 are downloadable. As for the assessment of the quality of these datasets, deeper inspections at single dataset and metadata level should be made.

According to the INSPIRE roadmap, by 21 October 2020, Member States shall make discoverable (in the INSPIRE Geoportal) and downloadable their harmonised buildings datasets, conformant to the INSPIRE core data model. However, as explained at the beginning of this section, the usability of these datasets, despite their formal conformance to INSPIRE, may be reduced because of the non-obligatoriness of their attributes. Therefore, data providers should be encouraged to provide meaningful values for all the attributes.

In this context, this exercise proved that the availability of georeferenced data at building level offers a wide range of uses to support policymakers. The main difficulty is represented by the need to download individual files for each municipality and then ingest them into a spatial database to perform GIS analyses.

4.2 Top-down approach

Statistical regression techniques allow estimating the influence of structural features of buildings, occupants' characteristics and climate conditions on indicators of energy performance in buildings at local level (e.g. NUTS3 and municipality). The results of the regression analysis inform about the relative influence of these factors on the energy performance of buildings and can be used to downscale aggregated consumption figures from national to local scale.

Data on building and household characteristics are available at different geographical levels, depending on the country. Similarly, indicator definitions and their thematic detail may vary from country to country. Therefore, a thorough work of harmonisation has to be carried out in order to produce indicators, which are comparable across Europe. In some cases, in order to increase the geographical detail, downscaling techniques may be applied, making use of proxies such as population counts or density. Optionally, detailed data collected from cadastral databases (or equivalent national sources) can be used as ancillary sources when available.

This approach allows the construction of detailed maps of energy consumption levels, and building/dwelling characteristics as of now (reference year of their current status is typically between 2010 and 2015) and under expected future projections (2020, 2030 or 2050).

Minimum steps for carrying out the downscaling procedure include:

- Data preparation (indicators on building/dwelling and household characteristics, and energy consumption), including:
    - collection of raw data from National and Regional Statistical Offices, or similar;
    - harmonisation of geography;
    - translation and harmonisation of thematic detail (metadata preparation).
- Selection of sample to estimate the regression model.
- Data exploration and check for:
    - outliers;
    - collinearity;
    - dependency;
    - balanced data.
- Selection procedure for the random part of the model.
- Selection procedure for the fixed part of the model.
- Estimation of coefficients of the final model.
- Downscaling of aggregated indicators at sub-national level.

In Figure 36 and Figure 37 we present the results of two statistical regression models estimated for NUTS3 regions in Belgium, Finland, France, Italy, the Netherlands, Poland, Portugal and Sweden.

Model I1 is a Generalised Linear Model and model I2 is a Generalised Linear Mixed Model. They are both estimated with Bayesian techniques in the R statistical environment, using the INLA package (Rue et al., 2009).

The dependent variable is the average annual gas consumption per dwelling, whereas the independent variables are: Heating Degree Days, Cooling Degree Days, percentage of dwellings built after 1990, percentage of dwellings not occupied, percentage of households with children and percentage of single dwellings. Model I2 also includes a mixed effect component related to the country to which the NUTS3 belongs.

The independent variables are based on data from official sources (National Statistical Offices) and collected mainly through the latest available Census (year 2011). The measured annual gas consumption is collected either from the energy provider or from reference sources, such as the Covenant of Mayors.

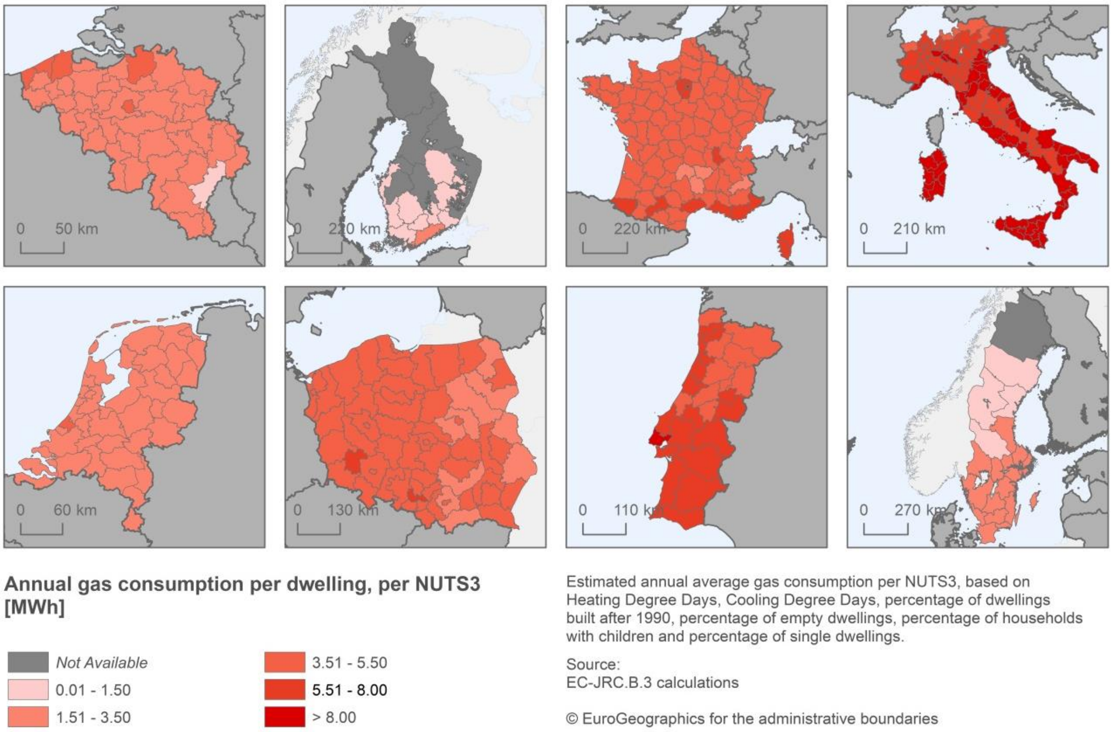

Figure 36. Estimated annual average gas consumption per NUTS3, based on model I1.

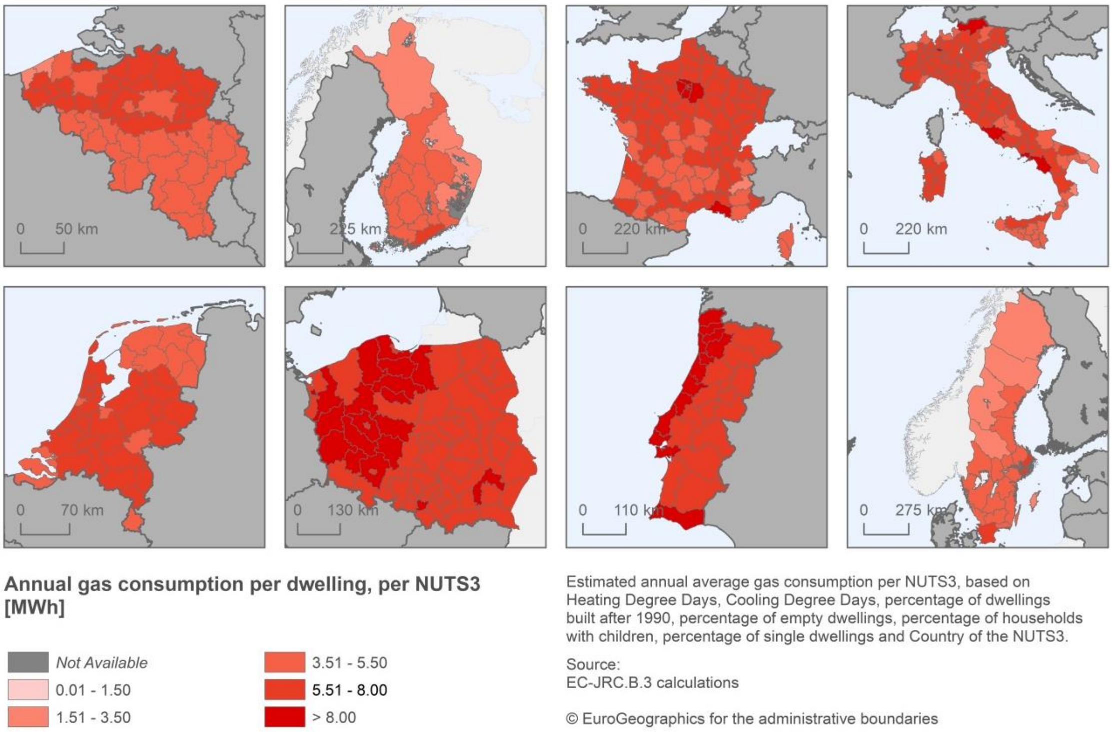

Figure 37. Estimated annual average gas consumption per NUTS3, based on model I2.

Figure 38 and Figure 39 below exemplify the importance of the country effect, focusing on the visual representation of the observed data.

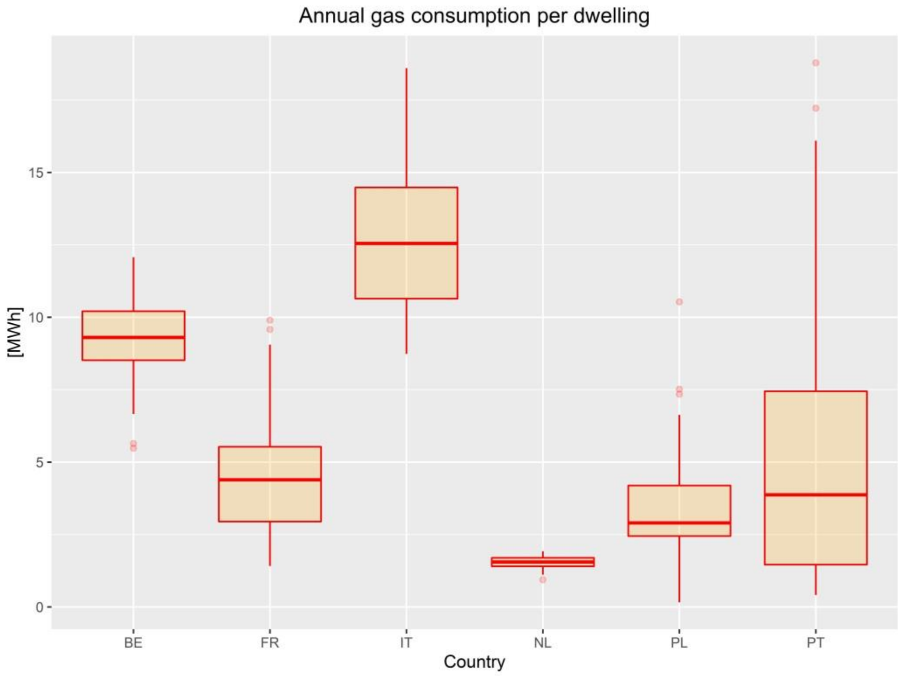

Figure 38. Boxplot of observed annual gas consumption per dwelling, per Country.

The boxplot in Figure 39 shows the values of the response variable (annual gas consumption per dwelling), highlighting the degree of variability across the considered countries. Observed data reveal that the effect of some variables is different across country.

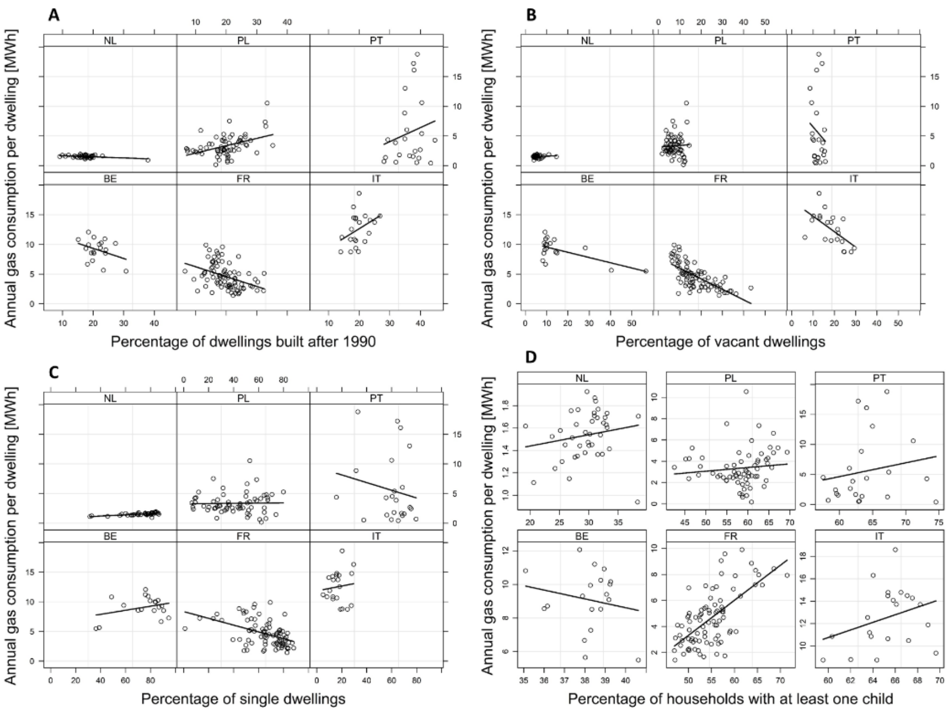

Figure 39. Plot of observed annual gas consumption per dwelling versus a selection of covariates, conditional on Country. Percentage of dwellings built after 1990 (A), Percentage of vacant dwellings (B), Percentage of single dwellings (C) and Percentage of households with at least one child (D). Linear regression lines are added for visual interpretation.

From the statistical analysis of the two fitted models, important variables are:

- for model I1: Heating Degree Days (negative effect), Percentage of households with at least one child (positive effect) and Percentage of single dwellings (negative effect);
- for model I2: Cooling Degree Days (negative effect), Percentage of vacant dwellings (negative effect), Percentage of households with at least one child (positive effect) and Percentage of single dwellings (negative effect) The other covariates are less important.

Similar models can be estimated for electricity consumption and total energy consumption.

This approach can give useful indication of the average level of energy consumption of relatively small territories (sub-regional level), highlighting the role played by climate and characteristics related to the built environment and their occupants.

This type of model is relatively quick to estimate and is based on data that can be easily retrieved from official sources. Nevertheless, data preparation, including data harmonisation, remains the most challenging and time-consuming phase.

To benefit from these models and apply them on a larger scale, the following issues have to be addressed:

- Energy consumption data at disaggregated level remain the most difficult item to retrieve. Considering the importance of the country effect, in order to estimate these models, it is necessary to have a representative sample of geographical units of analysis (NUTS3) per country.
- Metadata and harmonisation of definitions have to be ensured to allow for the estimation of the model across different countries.

In order to get more refined results at this geographical level (NUTS3), it is recommended to increase the availability of stratified data (e.g. construction period of dwellings that are single dwellings, etc.).

5 Conclusions

European regions and cities will be major players for climate/energy action in the EU and globally. To achieve Europe's ambition to reduce GHG emissions by 55% by 2030, an accelerated deployment of energy efficiency measures, electrification, more renewables and new concepts of mobility are needed. In this context, buildings are the largest single energy consumer in the EU, accounting for 40% of energy consumption and 36% of CO_2 emissions. Considering that half of the building stock was built prior to the introduction of the first thermal regulation in 1976, a drastic increase of the renovation rate, compared to the current trend, is necessary in the coming years to meet the EGD ambitions.

Buildings can be optimised in relation to the local climate and the energy demand can be reduced by 70% compared to current levels. The process will have huge implications on both the economy and society, thus requiring a holistic approach that includes technical, economic, social and behavioural as well as regulatory and financial aspects in order to ensure effective policies. The analysis of the impacts of climate change on the future energy demand of regions is fundamental to assess their resilience and the related social repercussions of additional concern. Boosting the energy performance of buildings will improve the living conditions of citizens and support a wide array of sectors of our economy. A decisive recovery action plan is under preparation to counter the negative effects of the crisis and support the economic rebound; smart cities and communities are seen as an effective recovery area to support the affected regions.

In this context, and in view of supporting the upcoming recovery action plan, a new collection of harmonised data adopting a top-down approach and downscaling national data to local level will be particularly useful. This collection will allow the mapping of the building stock characteristics at local level and can provide elements to discuss the main opportunities and barriers to energy renovations.

The activity reported in this report will be further developed and complemented by the JRC work programme 2021-2022 within the project “climate neutral smart cities transition”. For instance, we plan to complement the information collected here by labelling the potential Indoor Environmental Quality (IEQ) of buildings located, in relation to contextual factors (such as climate, exposure to pollutant sources) and statistics about the characteristics and age of buildings' systems. This approach would provide an indication of European areas where the risk of poor level of IEQ is higher and of the number/type of buildings that would need renovation to tackle this issue. The next step will be to create a new frame of priorities to meet the needs of refurbishing activities to counteract both poor energy efficiency and IEQ conditions. All this information will have a relevant effect on the policy scenario, which should be reconciled with our environmental targets and support the adaptability of the sustainable built environment.

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List of abbreviations and definitions

EPBD	Energy Performance of Building Directive
EED	Energy Efficiency Directive
EE	Energy Efficiency
EGD	European Green Deal
IEQ	Indoor Environmental Quality
INSPIRE	Infrastructure for Spatial Information in the European Community
NZEB	Nearly Zero Energy Building
RES	Renewable Energy Systems
TMY	Typical Meteorological Year

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Annexes

Annex 1. Energy savings and investment costs associated to cost-optimal and NZEB level

NUTS2	Single-Family Houses (1961-1980)				Multi-Family Houses (1961-1980)			
	Cost-Optimal level		NZEB level		Cost-Optimal level		NZEB level	
	Energy saving	Investment costs [€/m2]	Energy saving	Investment costs [€/m2]	Energy saving	Investment costs [€/m2]	Energy saving	Investment costs [€/m2]
AT11	80%	438	65%	367	70%	242	55%	234
AT12	80%	502	65%	422	70%	278	55%	269
AT13	80%	560	65%	470	70%	310	55%	300
AT21	80%	519	65%	436	70%	287	55%	278
AT22	80%	512	65%	430	70%	284	55%	275
AT31	80%	534	65%	448	70%	295	55%	286
AT32	80%	510	65%	428	70%	282	55%	273
AT33	80%	512	65%	430	70%	283	55%	274
AT34	80%	544	65%	457	70%	301	55%	291
BE10	60%	629	90%	854	37%	450	85%	506
BE21	60%	641	90%	863	37%	454	90%	536
BE22	60%	474	90%	742	37%	390	90%	461
BE23	60%	556	90%	803	37%	423	90%	499
BE24	60%	612	90%	843	37%	443	90%	524
BE25	60%	516	90%	774	37%	407	90%	481
BE31	60%	571	90%	814	37%	428	85%	482
BE32	60%	370	90%	655	37%	345	85%	388
BE33	60%	413	90%	693	37%	365	85%	410
BE34	60%	386	90%	670	37%	352	85%	397
BE35	60%	364	90%	650	37%	342	85%	385
BG31	60%	186	56%	181	60%	130	41%	86
BG32	60%	217	56%	212	60%	152	41%	101
BG33	60%	223	56%	218	60%	156	41%	104
BG34	60%	220	56%	215	60%	154	41%	103
BG41	60%	248	57%	243	60%	173	44%	130
BG42	60%	195	57%	191	60%	136	44%	102
HR03	65%	209	84%	375	60%	147	79%	196
HR04	65%	191	84%	341	60%	133	79%	178
CY00	85%	355	73%	254	85%	175	66%	125
CZ01	85%	290	92%	451	85%	255	91%	288
CZ02	85%	193	92%	301	85%	170	91%	192
CZ03	85%	192	92%	299	85%	169	91%	191
CZ04	85%	164	92%	254	85%	144	91%	162
CZ05	85%	174	92%	271	85%	153	91%	173
CZ06	85%	196	92%	305	85%	172	91%	195
CZ07	85%	173	92%	269	85%	152	91%	172
CZ08	85%	173	92%	269	85%	152	91%	172
DK01	30%	290	87%	588	50%	283	87%	492
DK02	30%	268	87%	545	50%	262	87%	458
DK03	30%	264	87%	537	50%	259	87%	450
DK04	30%	263	87%	534	50%	257	88%	450
DK05	30%	264	87%	536	50%	258	88%	454
EE00	50%	210	90%	240	40%	127	77%	218
FI19	60%	356	49%	296	15%	88	53%	234
FI1B	60%	403	49%	336	15%	100	53%	265
FI1C	60%	352	49%	293	15%	87	53%	231
FI1D	60%	348	49%	290	15%	86	53%	229
FI20	60%	332	49%	277	15%	82	53%	218
FR10	65%	456	75%	526	70%	300	73%	310
FR21	65%	339	75%	392	70%	223	73%	231
FR22	65%	333	75%	384	70%	219	73%	226
FR23	65%	349	75%	403	70%	230	73%	237
FR24	65%	345	75%	398	70%	227	73%	235
FR25	65%	322	75%	371	70%	212	73%	219
FR26	65%	336	75%	388	70%	221	73%	229
FR30	65%	351	75%	405	70%	231	73%	239

FR41	65%	350	75%	403	70%	230	73%	238
FR42	65%	372	75%	430	70%	245	73%	253
FR43	65%	345	75%	398	70%	227	73%	234
FR51	65%	339	75%	391	70%	223	73%	230
FR52	65%	326	75%	376	70%	214	73%	222
FR53	65%	313	75%	361	70%	206	73%	213
FR61	65%	345	75%	398	70%	227	73%	234
FR62	65%	362	75%	418	70%	238	73%	246
FR63	65%	325	75%	375	70%	214	73%	221
FR71	65%	382	75%	440	70%	251	73%	259
FR72	65%	366	75%	422	70%	241	73%	249
FR81	65%	328	75%	378	70%	215	73%	223
FR82	65%	388	75%	448	70%	256	73%	264
FR83	65%	297	75%	343	70%	196	73%	202
DE11	75%	675	82%	783	50%	413	81%	517
DE12	75%	645	82%	748	50%	395	81%	494
DE13	75%	622	82%	722	50%	381	81%	476
DE14	75%	634	82%	736	50%	388	81%	486
DE21	75%	657	82%	763	50%	403	81%	504
DE22	75%	570	82%	662	50%	349	81%	437
DE23	75%	598	82%	694	50%	366	81%	458
DE24	75%	559	82%	649	50%	342	81%	428
DE25	75%	591	82%	685	50%	362	81%	452
DE26	75%	570	82%	662	50%	349	81%	437
DE27	75%	583	82%	677	50%	357	81%	447
DE30	75%	560	82%	650	50%	343	81%	429
DE40	75%	453	82%	526	50%	277	81%	347
DE50	75%	653	82%	758	50%	400	81%	500
DE60	75%	691	82%	801	50%	423	81%	529
DE71	75%	600	82%	696	50%	367	81%	459
DE72	75%	559	82%	649	50%	343	81%	429
DE73	75%	585	82%	678	50%	358	81%	448
DE80	75%	442	82%	513	50%	271	81%	338
DE91	75%	591	82%	686	50%	362	81%	453
DE92	75%	569	82%	660	50%	348	81%	436
DE93	75%	554	82%	643	50%	339	81%	424
DE94	75%	548	82%	635	50%	335	81%	419
DEA1	75%	603	82%	700	50%	370	81%	462
DEA2	75%	582	82%	675	50%	356	81%	446
DEA3	75%	572	82%	664	50%	351	81%	438
DEA4	75%	562	82%	652	50%	344	81%	431
DEA5	75%	569	82%	660	50%	348	81%	436
DEB1	75%	543	82%	631	50%	333	81%	416
DEB2	75%	547	82%	635	50%	335	81%	419
DEB3	75%	602	82%	699	50%	369	81%	461
DEC0	75%	537	82%	624	50%	329	81%	412
DED2	75%	467	82%	542	50%	286	81%	358
DED4	75%	444	82%	516	50%	272	81%	340
DED5	75%	479	82%	555	50%	293	81%	367
DEE0	75%	468	82%	543	50%	287	81%	358
DEF0	75%	578	82%	671	50%	354	81%	443
DEG0	75%	459	82%	533	50%	281	81%	352
GR11	80%	210	55%	200	75%	140	26%	95
GR12	80%	238	55%	227	75%	159	26%	108
GR13	80%	234	55%	224	75%	156	26%	106
GR14	80%	246	55%	235	75%	164	26%	112
GR21	70%	492	44%	208	70%	246	0%	0
GR22	70%	437	44%	184	70%	218	0%	0
GR23	70%	515	44%	217	70%	257	0%	0
GR24	70%	564	44%	238	70%	282	0%	0
GR25	70%	465	44%	196	70%	233	0%	0
GR30	70%	410	44%	173	70%	205	0%	0
GR41	70%	425	44%	179	70%	212	0%	0
GR42	70%	410	44%	173	70%	205	0%	0

GR43	70%	411	44%	173	70%	205	0%	0
HU10	60%	178	70%	356	50%	110	49%	110
HU21	60%	178	70%	356	50%	110	49%	110
HU22	60%	174	70%	348	50%	107	49%	107
HU23	60%	163	70%	326	50%	101	49%	101
HU31	60%	171	70%	342	50%	106	49%	106
HU32	60%	164	70%	328	50%	101	49%	101
HU33	60%	168	70%	336	50%	104	49%	104
IE01	60%	334	85%	473	60%	276	80%	321
IE02	60%	410	85%	581	60%	339	80%	394
ITC1	85%	542	79%	459	55%	202	72%	276
ITC2	85%	540	79%	458	55%	201	72%	275
ITC3	85%	553	79%	469	55%	206	72%	281
ITC4	85%	590	79%	500	55%	220	72%	300
ITF1	80%	379	74%	360	55%	220	68%	216
ITF2	80%	354	74%	337	55%	206	68%	202
ITF3	80%	337	74%	320	55%	195	68%	192
ITF4	80%	347	74%	330	55%	201	68%	198
ITF5	80%	381	74%	361	55%	221	68%	217
ITF6	80%	299	74%	284	55%	174	68%	171
ITG1	80%	355	74%	337	55%	206	68%	202
ITG2	80%	372	74%	353	55%	216	68%	212
ITH1	85%	627	79%	531	55%	234	72%	319
ITH2	85%	556	79%	471	55%	207	72%	283
ITH3	85%	547	79%	463	55%	204	72%	278
ITH4	85%	552	79%	467	55%	206	72%	280
ITH5	85%	580	79%	492	55%	216	72%	295
ITI1	85%	497	79%	421	55%	185	72%	253
ITI2	80%	398	74%	379	55%	231	68%	227
ITI3	80%	408	74%	387	55%	237	68%	232
ITI4	80%	431	74%	410	55%	250	68%	246
LV00	75%	200	73%	200	35%	150	59%	200
LT00	60%	215	64%	235	30%	130	67%	200
LU00	40%	355	80%	550	40%	386	70%	500
MT00	80%	520	56%	364	75%	300	43%	172
NL11	35%	282	88%	740	35%	234	83%	444
NL12	35%	267	88%	700	35%	221	83%	420
NL13	35%	276	88%	724	35%	228	83%	434
NL21	35%	277	88%	726	35%	229	83%	436
NL22	35%	282	88%	740	35%	234	83%	444
NL23	35%	266	88%	698	35%	220	83%	419
NL31	35%	318	88%	835	35%	264	83%	501
NL32	35%	309	88%	810	35%	256	83%	486
NL33	35%	322	88%	844	35%	267	83%	506
NL34	35%	293	88%	767	35%	242	83%	460
NL41	35%	304	88%	797	35%	252	83%	478
NL42	35%	281	88%	738	35%	233	83%	443
PL11	75%	267	71%	272	50%	129	57%	134
PL12	75%	214	71%	218	50%	104	57%	107
PL21	75%	275	71%	280	50%	134	57%	138
PL22	75%	342	71%	349	50%	166	57%	172
PL43	75%	240	71%	245	50%	117	57%	121
PL32	75%	269	71%	274	50%	131	57%	135
PL33	75%	221	71%	226	50%	107	57%	111
PL34	75%	283	71%	289	50%	137	57%	142
PL41	75%	329	71%	335	50%	160	57%	165
PL42	75%	267	71%	272	50%	129	57%	134
PL31	75%	265	71%	271	50%	129	57%	133
PL51	75%	313	71%	319	50%	152	57%	157
PL52	75%	431	71%	439	50%	209	57%	216
PL61	75%	275	71%	280	50%	134	57%	138
PL62	75%	242	71%	247	50%	117	57%	121
PL63	75%	307	71%	313	50%	149	57%	154
PT11	85%	401	45%	280	70%	280	58%	187

PT15	85%	367	45%	256	70%	256	58%	171
PT16	85%	405	45%	283	70%	283	58%	189
PT17	85%	549	45%	383	70%	383	58%	256
PT18	85%	437	45%	305	70%	305	58%	203
PT20	85%	362	45%	252	70%	252	58%	168
PT30	85%	488	45%	341	70%	341	58%	227
RO11	60%	96	75%	134	60%	67	69%	89
RO12	60%	113	75%	157	60%	79	69%	105
RO21	60%	79	75%	111	60%	55	69%	74
RO22	60%	111	75%	155	60%	77	69%	103
RO31	60%	94	75%	131	60%	66	69%	87
RO32	60%	215	75%	300	60%	150	69%	200
RO41	60%	120	75%	168	60%	84	69%	112
RO42	60%	135	75%	188	60%	94	69%	125
SK01	90%	595	85%	562	80%	337	66%	291
SK02	90%	397	85%	375	80%	225	66%	194
SK03	90%	413	85%	390	80%	234	66%	202
SK04	90%	395	85%	373	80%	224	66%	193
SI01	65%	194	69%	213	60%	135	59%	135
SI02	65%	206	69%	227	60%	145	59%	145
ES11	80%	425	77%	409	75%	278	70%	237
ES12	80%	526	77%	506	75%	344	70%	293
ES13	80%	457	77%	440	75%	299	70%	255
ES21	80%	553	77%	532	75%	361	70%	308
ES22	80%	513	77%	493	75%	335	70%	286
ES23	80%	455	77%	437	75%	297	70%	254
ES24	80%	454	77%	436	75%	297	70%	253
ES30	80%	520	77%	500	75%	340	70%	290
ES41	80%	432	77%	416	75%	283	70%	241
ES42	80%	401	77%	385	75%	262	70%	224
ES43	85%	366	77%	426	70%	256	70%	239
ES51	85%	505	78%	587	70%	352	72%	329
ES52	85%	416	78%	484	70%	290	72%	271
ES53	85%	383	78%	445	70%	267	72%	249
ES61	85%	430	78%	500	70%	300	72%	280
ES62	85%	414	78%	481	70%	289	72%	269
ES70	85%	393	78%	457	70%	274	72%	256
SE11	60%	427	78%	477	15%	106	75%	424
SE12	60%	409	78%	457	15%	102	75%	406
SE21	60%	384	78%	429	15%	95	75%	381
SE22	60%	405	78%	452	15%	100	75%	402
SE23	60%	405	78%	452	15%	101	75%	402
SE31	60%	395	78%	441	15%	98	75%	392
SE32	60%	396	78%	442	15%	98	75%	393
SE33	60%	403	78%	450	15%	100	75%	400

Annex 2. Energy savings potential and associated capital expenditure

NUTS2	Primary energy saving potential [TWh]			Capital expenditure [M€]		
	Theoretical cost-optimal	Theoretical NZEB	Scenario 0 (renovation rate of 1%)	Theoretical cost-optimal	Theoretical NZEB	Scenario 0 (renovation rate of 1%)
AT11	1,85	1,50	0,56	4.488	3.793	1.346
AT12	9,22	7,45	2,77	24.786	21.424	7.436
AT13	6,40	5,04	1,92	16.693	16.065	5.008
AT21	4,06	3,28	1,22	8.969	7.781	2.691
AT22	7,63	6,13	2,29	16.057	14.238	4.817
AT31	7,89	6,36	2,37	21.561	18.789	6.468
AT32	3,76	3,02	1,13	6.840	6.085	2.052
AT33	5,29	4,24	1,59	9.325	8.260	2.798
AT34	2,31	1,86	0,69	5.421	4.721	1.626
BE10	4,10	7,75	1,23	17.157	20.078	5.147
BE21	6,76	11,51	2,03	29.875	38.474	8.962
BE22	3,32	5,25	1,00	10.548	16.131	3.164
BE23	6,31	9,67	1,89	21.845	30.252	6.554
BE24	4,80	7,35	1,44	18.059	24.096	5.418
BE25	5,30	8,30	1,59	17.281	25.051	5.184
BE31	1,69	2,43	0,51	5.380	7.455	1.614
BE32	6,82	9,21	2,05	14.260	20.765	4.278
BE33	5,55	7,99	1,66	12.582	17.931	3.775
BE34	1,52	2,14	0,46	2.816	4.274	845
BE35	2,44	3,39	0,73	4.749	7.133	1.425
BG31	2,70	2,50	0,81	4.763	4.632	1.429
BG32	2,40	2,21	0,72	5.308	5.135	1.593
BG33	2,32	2,12	0,70	5.512	5.291	1.654
BG34	2,53	2,31	0,76	6.011	5.779	1.803
BG41	6,24	5,79	1,87	13.268	12.662	3.980
BG42	4,27	4,02	1,28	7.507	7.252	2.252
HR03	3,96	5,12	1,19	6.547	11.039	1.964
HR04	10,07	13,06	3,02	11.475	19.007	3.443
CY00	2,80	2,34	0,84	5.493	3.929	1.648
CZ01	10,43	11,20	3,13	9.129	10.636	2.739
CZ02	9,68	10,44	2,90	5.917	8.896	1.775
CZ03	10,29	11,09	3,09	5.585	8.086	1.676
CZ04	10,14	10,93	3,04	4.601	6.395	1.380
CZ05	12,63	13,61	3,79	6.351	9.085	1.905
CZ06	14,66	15,80	4,40	7.940	11.330	2.382
CZ07	10,64	11,47	3,19	5.253	7.686	1.576
CZ08	13,49	14,53	4,05	5.918	8.416	1.775
DK01	4,90	8,81	1,47	19.817	33.335	5.945
DK02	2,64	5,44	0,79	10.463	17.703	3.139
DK03	3,99	7,94	1,20	15.316	25.547	4.595
DK04	4,05	8,09	1,22	15.174	25.705	4.552
DK05	2,15	4,27	0,65	7.695	12.862	2.308
EE00	5,15	10,93	1,55	6.301	8.311	1.890
FI19	6,23	6,00	1,87	14.489	13.372	4.347
FI1B	2,74	6,78	0,82	7.630	14.343	2.289
FI1C	4,97	5,23	1,49	11.973	11.682	3.592
FI1D	7,14	6,49	2,14	14.382	12.824	4.315
FI20	0,10	0,09	0,03	279	241	84
FR10	63,43	68,02	19,03	116.913	125.115	35.074
FR21	8,81	10,03	2,64	12.956	14.795	3.887
FR22	11,05	12,60	3,32	16.932	19.374	5.080
FR23	11,05	12,52	3,32	17.395	19.781	5.219
FR24	13,72	15,66	4,12	25.223	28.879	7.567
FR25	8,59	9,79	2,58	13.691	15.664	4.107
FR26	10,49	11,94	3,15	15.862	18.124	4.759
FR30	24,52	27,90	7,36	38.032	43.423	11.410
FR41	16,57	18,61	4,97	21.859	24.677	6.558
FR42	11,81	13,14	3,54	17.199	19.239	5.160
FR43	7,93	8,92	2,38	10.862	12.291	3.259

FR51	17,70	20,15	5,31	33.543	38.323	10.063
FR52	16,56	18,83	4,97	30.247	34.517	9.074
FR53	8,94	10,19	2,68	16.041	18.352	4.812
FR61	13,95	15,76	4,19	30.993	35.173	9.298
FR62	15,28	17,34	4,58	29.464	33.564	8.839
FR63	4,77	5,44	1,43	7.397	8.470	2.219
FR71	41,82	46,71	12,55	62.330	69.982	18.699
FR72	9,88	11,23	2,96	14.576	16.627	4.373
FR81	15,41	17,34	4,62	24.863	28.124	7.459
FR82	30,59	33,63	9,18	49.915	55.125	14.975
FR83	1,38	1,54	0,41	2.573	2.896	772
DE11	20,80	26,94	6,24	79.022	94.437	23.707
DE12	14,32	18,84	4,30	52.133	62.489	15.640
DE13	13,00	16,49	3,90	41.177	49.023	12.353
DE14	11,17	13,66	3,35	35.599	42.096	10.680
DE21	23,77	33,11	7,13	77.814	94.326	23.344
DE22	7,57	9,11	2,27	22.583	26.628	6.775
DE23	6,75	8,52	2,03	20.365	24.220	6.109
DE24	7,00	8,78	2,10	19.450	23.105	5.835
DE25	9,20	12,56	2,76	28.836	34.813	8.651
DE26	8,20	9,80	2,46	25.874	30.473	7.762
DE27	11,57	14,73	3,47	32.223	38.384	9.667
DE30	13,67	21,79	4,10	41.115	51.303	12.335
DE40	13,66	17,19	4,10	32.958	39.179	9.887
DE50	3,93	5,15	1,18	13.198	15.810	3.960
DE60	7,40	11,25	2,22	28.351	34.999	8.505
DE71	19,25	25,90	5,77	65.095	78.365	19.528
DE72	6,34	7,62	1,90	19.513	23.005	5.854
DE73	8,06	9,89	2,42	23.781	28.137	7.134
DE80	9,18	11,65	2,75	20.918	24.904	6.275
DE91	9,53	12,27	2,86	29.450	35.154	8.835
DE92	12,42	16,16	3,73	37.977	45.426	11.393
DE93	10,25	12,47	3,07	31.237	36.907	9.371
DE94	14,15	17,39	4,24	44.249	52.378	13.275
DEA1	24,23	33,16	7,27	86.918	104.984	26.075
DEA2	22,59	29,51	6,78	75.619	90.517	22.686
DEA3	13,59	17,46	4,08	44.397	52.977	13.319
DEA4	11,84	14,87	3,55	35.814	42.557	10.744
DEA5	19,67	26,43	5,90	59.051	71.066	17.715
DEB1	9,50	11,40	2,85	27.987	32.985	8.396
DEB2	3,46	4,12	1,04	9.851	11.597	2.955
DEB3	11,44	13,94	3,43	40.845	48.271	12.253
DEC0	6,85	8,19	2,05	19.919	23.465	5.976
DED2	7,63	10,34	2,29	19.279	23.241	5.784
DED4	7,67	10,33	2,30	17.010	20.480	5.103
DED5	4,33	6,28	1,30	11.328	13.846	3.399
DEE0	12,62	16,07	3,78	31.070	37.014	9.321
DEF0	16,56	21,37	4,97	49.202	58.759	14.761
DEG0	12,37	15,64	3,71	28.826	34.293	8.648
GR11	2,22	1,44	0,67	3.761	3.100	1.128
GR12	6,59	4,25	1,98	13.230	10.801	3.969
GR13	1,49	0,97	0,45	2.011	1.671	603
GR14	2,68	1,76	0,80	5.308	4.474	1.592
GR21	1,12	0,55	0,34	4.480	1.950	1.344
GR22	0,42	0,16	0,13	2.333	869	700
GR23	1,82	0,88	0,55	9.062	3.965	2.719
GR24	2,08	1,01	0,62	8.478	3.701	2.543
GR25	1,69	0,84	0,51	7.628	3.295	2.288
GR30	10,00	4,91	3,00	43.436	18.410	13.031
GR41	0,50	0,27	0,15	2.496	1.065	749
GR42	0,82	0,38	0,24	3.358	1.446	1.007
GR43	0,92	0,44	0,28	6.948	2.998	2.085
HU10	11,43	11,56	3,43	9.127	26.028	2.738
HU21	5,81	6,18	1,74	5.047	9.314	1.514

HU22	4,76	4,97	1,43	4.042	8.469	1.213
HU23	5,18	5,53	1,55	4.249	7.592	1.275
HU31	6,97	7,49	2,09	5.667	10.662	1.700
HU32	7,79	8,11	2,34	6.632	11.158	1.990
HU33	7,31	7,78	2,19	6.447	11.571	1.934
IE01	3,22	4,56	0,97	6.826	9.636	2.048
IE02	9,83	13,84	2,95	24.700	34.403	7.410
ITC1	31,61	32,32	9,48	62.629	59.629	18.789
ITC2	1,52	1,62	0,45	1.731	1.746	519
ITC3	7,38	8,21	2,22	19.421	20.645	5.826
ITC4	53,55	59,16	16,07	115.341	121.463	34.602
ITF1	6,11	6,18	1,83	14.141	13.558	4.242
ITF2	1,59	1,58	0,48	3.437	3.288	1.031
ITF3	14,88	16,35	4,46	41.729	40.377	12.519
ITF4	10,59	10,89	3,18	37.674	36.179	11.302
ITF5	2,26	2,30	0,68	5.982	5.739	1.795
ITF6	6,51	6,52	1,95	17.755	17.001	5.327
ITG1	13,47	13,87	4,04	50.186	48.203	15.056
ITG2	4,91	4,85	1,47	19.280	18.436	5.784
ITH1	3,69	4,08	1,11	5.498	5.782	1.649
ITH2	4,15	4,50	1,25	6.283	6.450	1.885
ITH3	28,03	29,61	8,41	62.239	61.728	18.672
ITH4	7,32	7,69	2,20	17.152	16.872	5.146
ITH5	22,11	23,96	6,63	56.391	57.873	16.917
ITI1	17,26	18,45	5,18	40.481	40.808	12.144
ITI2	3,61	3,73	1,08	9.557	9.181	2.867
ITI3	6,33	6,47	1,90	17.336	16.639	5.201
ITI4	18,28	19,71	5,48	60.719	58.625	18.216
LV00	5,27	7,12	1,58	8.137	10.060	2.441
LT00	6,53	8,83	1,96	14.568	17.748	4.370
LU00	1,32	2,57	0,40	6.173	9.187	1.852
MT00	0,71	0,49	0,21	3.893	2.698	1.168
NL11	1,84	4,61	0,55	6.201	15.923	1.860
NL12	1,93	4,86	0,58	6.512	16.826	1.954
NL13	1,58	3,97	0,47	5.272	13.694	1.582
NL21	3,33	8,37	1,00	11.545	29.671	3.464
NL22	5,45	13,66	1,63	20.464	52.064	6.139
NL23	0,87	2,18	0,26	3.266	8.549	980
NL31	3,15	7,89	0,94	13.714	34.715	4.114
NL32	5,61	13,71	1,68	26.013	58.351	7.804
NL33	8,25	20,48	2,47	38.330	93.162	11.499
NL34	1,14	2,87	0,34	4.076	10.572	1.223
NL41	7,23	18,13	2,17	28.980	74.140	8.694
NL42	3,40	8,51	1,02	12.940	32.696	3.882
PL11	7,94	8,74	2,38	8.310	8.564	2.493
PL12	16,49	17,67	4,95	14.095	14.492	4.229
PL21	11,07	11,38	3,32	12.822	13.141	3.846
PL22	14,97	16,25	4,49	20.214	20.805	6.064
PL43	6,64	6,89	1,99	7.664	7.860	2.299
PL32	7,75	7,72	2,33	8.981	9.186	2.694
PL33	4,78	4,80	1,43	4.770	4.881	1.431
PL34	4,91	4,99	1,47	5.512	5.645	1.653
PL41	9,71	10,14	2,91	14.363	14.738	4.309
PL42	4,94	5,27	1,48	5.447	5.598	1.634
PL31	3,43	3,55	1,03	3.666	3.760	1.100
PL51	8,26	8,83	2,48	10.741	11.042	3.222
PL52	3,64	3,70	1,09	7.028	7.197	2.108
PL61	5,85	6,23	1,76	6.730	6.916	2.019
PL62	4,60	4,80	1,38	4.329	4.442	1.299
PL63	6,65	7,10	1,99	7.873	8.092	2.362
PT11	9,45	5,22	2,83	44.071	30.639	13.221
PT15	0,49	0,26	0,15	5.531	3.855	1.659
PT16	6,51	3,49	1,95	32.296	22.507	9.689
PT17	3,45	2,43	1,03	40.325	27.404	12.098

PT18	1,64	0,89	0,49	11.162	7.772	3.349
PT20	0,31	0,17	0,09	2.416	1.684	725
PT30	0,32	0,17	0,10	3.465	2.416	1.040
RO11	4,35	5,35	1,31	4.561	6.307	1.368
RO12	4,56	5,65	1,37	5.054	7.008	1.516
RO21	32,90	39,54	9,87	26.711	36.508	8.013
RO22	3,80	4,72	1,14	5.497	7.642	1.649
RO31	4,68	5,85	1,41	5.588	7.779	1.676
RO32	3,05	3,66	0,91	8.622	11.782	2.587
RO41	3,42	4,29	1,03	5.061	7.055	1.518
RO42	2,98	3,69	0,89	4.943	6.854	1.483
SK01	2,44	2,23	0,73	8.196	7.504	2.459
SK02	8,60	8,12	2,58	16.258	15.284	4.877
SK03	7,30	6,89	2,19	11.886	11.165	3.566
SK04	7,48	7,04	2,24	12.199	11.442	3.660
SI01	4,28	4,51	1,28	4.658	5.054	1.397
SI02	3,28	3,45	0,98	4.339	4.679	1.302
ES11	8,78	8,37	2,63	34.320	32.702	10.296
ES12	3,94	3,76	1,18	16.997	16.152	5.099
ES13	2,13	2,03	0,64	7.394	6.934	2.218
ES21	7,10	6,68	2,13	28.691	25.815	8.607
ES22	2,34	2,23	0,70	8.796	8.235	2.639
ES23	1,29	1,22	0,39	3.892	3.648	1.167
ES24	5,84	5,56	1,75	18.404	17.482	5.521
ES30	18,79	17,50	5,64	67.528	58.455	20.258
ES41	12,36	11,79	3,71	35.605	34.002	10.681
ES42	7,82	7,46	2,35	25.948	24.738	7.785
ES43	3,20	2,89	0,96	13.066	15.035	3.920
ES51	22,79	22,08	6,84	97.223	102.602	29.167
ES52	12,90	12,18	3,87	60.485	66.638	18.146
ES53	2,33	2,17	0,70	12.642	14.197	3.793
ES61	18,90	17,68	5,67	98.806	110.592	29.642
ES62	3,04	2,79	0,91	16.658	19.133	4.998
ES70	2,96	2,75	0,89	22.690	25.747	6.807
SE11	7,91	13,63	2,37	20.111	28.299	6.033
SE12	8,66	11,47	2,60	21.271	24.208	6.381
SE21	4,31	5,64	1,29	10.687	12.058	3.206
SE22	6,11	8,21	1,83	17.649	20.307	5.295
SE23	9,46	12,62	2,84	25.687	29.395	7.706
SE31	5,69	7,46	1,71	11.514	13.006	3.454
SE32	3,06	4,03	0,92	5.209	5.904	1.563
SE33	3,91	5,25	1,17	6.414	7.381	1.924

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