

The typology of the residential building stock of Montenegro and modelling its low-carbon transformation

Montenegro

Support for Low-Emission Development in South Eastern Europe (SLED)

REGIONAL ENVIRONMENTAL CENTER

WITH FUNDING FROM
AUSTRIAN DEVELOPMENT COOPERATION

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Support for Low-Emission Development in South Eastern Europe (SLED)

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The REC is implementing the project "Support for Low-Emission Development in South Eastern Europe" (SLED) to help policy makers in the project countries (Albania, the former Yugoslav Republic of Macedonia, Montenegro and Serbia) to establish realistic but ambitious decarbonisation pathways for their electricity and building sectors by 2030.

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Table of contents

PART 2

Modelling the transformation to a low-carbon residential building stock

List of figures

List of tables

Executive summary

Energy demand in the building sector represents a big challenge for Montenegro. In 2013, the sector was responsible for 23 percent of national final energy consumption and 37 percent of national electricity consumption. The quality of energy services delivered to residential buildings is poor. Most notably, only half of the dwelling floor area is heated in Montenegrin dwellings. The continued use of outdated wood stoves results in numerous environmental and health problems.

Montenegro is a contracting party to the Energy Community Treaty and is thus obliged to introduce EU energy efficiency legislation. Achieving the related targets requires more ambitious policy efforts and larger investments into demand-side energy efficiency than are being made at present.

The aim of the present publication is to provide information that will assist in the design of energy efficiency and climate mitigation policies for the residential building sector in Montenegro. We have identified 15 representative categories of residential buildings, calculated their thermal energy performance in three climate zones, designed standardised retrofitting packages, calculated possible energy savings, and defined the investments required by building type. We have identified the level and structure of final energy consumption at present and in the future by building age category, building type, climate zone and energy end use. We suggest two packages of policies in addition to the existing policies, which are aimed at transforming the residential building stock to zero-energy and zero-carbon levels in 2050 and 2070. We estimate the level of efforts required to achieve these goals in terms of the floor area affected and the investments required by actor and by policy tool. Finally, we evaluate energy savings, saved energy costs, avoided CO_2 emissions, and the cost-effectiveness of the policy packages.

In order to carry out the analysis at sector level, we designed and applied a bottom-up simulation model. The model is applicable up to 2030. We assessed only thermal energy services delivered to residential buildings — namely space heating, space cooling and water heating. We did not cover energy use for electrical appliances, lighting and cooking. We considered both direct and indirect CO_2 emissions in our analysis.

The model itself, with all the underlying input data, has been provided to national policy makers and experts to use and modify according to their needs. It is also available on request for use by other experts, subject to appropriate referencing and acknowledgement.

WHAT ARE THE CURRENT LEVELS AND FUTURE TRENDS OF FINAL ENERGY CONSUMPTION AND CO_2 EMISSIONS IN THE RESIDENTIAL BUILDING SECTOR?

According to our estimates, in 2015 final energy consumption in the residential sector for thermal energy services was 2.6 billion kWh, of which 24 percent was electricity and 76 percent was wood. The sector emitted 365,000 tonnes of CO_2 associated with electricity consumption. Final energy consumption, calculated on the basis of the geometrical and thermal characteristics of buildings as well as the characteristics of the energy systems installed, differed significantly from the estimated energy balance. Final energy consumption was therefore calibrated to the balance, correcting for the current level of thermal comfort — namely, partial floor area heated and cooled and the duration of space heating and cooling.

In the business-as-usual reference scenario, final energy consumption for thermal services will grow by around 2 percent between 2015 and 2030, when it will reach 2.7 billion kWh. In 2030, CO_2 emissions will be 60 percent of their 2015 level, due to the decreasing emission factor of electricity. There will be no significant changes in the structure of consumed energy sources. Energy demand in existing buildings is expected to decline, despite the increase in thermal comfort due to business-as-usual improvements, which take place once during the building lifetime. The average business-as-usual retrofitting rate of the building stock is 1.82 percent per year.

WHAT ARE THE PRIORITY SECTOR SEGMENTS FOR POLICY MAKING?

From a long-term perspective, it is important to ensure that buildings built between 1971 and 1990 are retrofitted. While these buildings will occupy 32 percent of the building floor area in 2030, they contribute 40 percent to the total final energy consumption and are therefore a clear priority for policy intervention.

New buildings will consume 10 percent of the final energy consumption in 2030, even though their floor area represents 19 percent of the total sector floor area. This estimate is made assuming that new buildings comply with the building code introduced in 2013, which is why policies that ensure the compliance of new buildings with the building code are also important.

Small buildings are a clear priority for policy making, since, in 2030, small buildings will be responsible for 83 percent of final energy consumption for thermal energy uses. Small buildings built in 1971–1990, 2001–2015, 1946–1970 and 1991–2000 are individually responsible for more than 10 percent of final energy consumption by that time.

In 2030, half the final energy consumption will originate from climate zone 1 (coastline), followed by climate zone 3 (mountains) and climate zone 2 (moderate zone). More than 80 percent of final energy consumption for thermal energy services will be attributed to space heating.

WHAT POLICY PACKAGES ARE POSSIBLE?

The SLED moderate scenario implies that, by 2070, the performance of all new and existing buildings will correspond to the performance after standard improvement 1, as defined in the present publication. The measures in standard improvement 1 comply with the requirements of the building code introduced in 2013. This improvement implies not only lower energy consumption, but also greater thermal comfort than is considered in the business-as-usual improvement.

To ensure that all existing buildings that remain in 2070 are retrofitted by this point we assume that Montenegro will introduce financial incentives for investors in the residential sector. These include the introduction of low-interest loans for 90 percent of households in detached and semi-detached houses and the introduction of grants for the remaining 10 percent of such households. They also include the introduction of loans for 10 percent of the currently retrofitted households in row (terraced) and multi-residential apartment buildings, and this share is assumed to have grown by 90 percent by 2070. The remaining households in row and multi-residential apartment buildings are assumed to obtain grants.

Due to high upfront investment costs, we recommend coupling the thermal efficiency improvement of existing buildings with their business-as-usual renovation where possible, in order to take advantage of costs that are anyway incurred. The retrofitting rate in the SLED moderate scenario is the same as in the reference scenario, which allows the maximum use of the business-as-usual investments. We assume that financial incentives will be provided to cover the share of eligible investment costs in better buildings, which is approximately equal to the share of the incremental investment costs in improvement 1 as compared to the business-as-usual improvement.

The SLED ambitious scenario supposes that by 2050 the performance of the majority of new and existing buildings will correspond to their performance following the ambitious improvement 2 defined in the present book. Improvement 2 implies even higher thermal comfort than improvement 1.

According to the scenario, in addition to the 2013 building code, Montenegro would introduce a more stringent building code in 2022 with requirements no lower than those of the measures of improvement 2. In order to prepare the market, Montenegro would introduce, from 2016, low-interest loans for the construction of new buildings that achieve a performance corresponding to the new building code. Similar to the SLED moderate scenario, the SLED ambitious scenario assumes the retrofitting, by 2050, of all existing buildings remaining by this time. Retrofitting would be carried out according to improvement 1 until 2022, and according to improvement 2 from 2023 to 2050.

To ensure the implementation of this retrofitting, Montenegro is assumed to introduce financial incentives for investors in the residential sector. Up to 2022, these financial incentives would be provided in order to achieve a level of performance according to improvement 1. After 2023 and up to 2050, the incentives would be provided in order to achieve a level of performance according to improvement 2.

The retrofitting rate in the SLED ambitious scenario is higher than the retrofitting rate in the reference scenario, which is why the incremental costs of the SLED ambitious scenario include the incremental investment costs of thermal efficiency retrofitting for a part of the retrofitted building stock, and the total investment costs of thermal efficiency retrofitting for the rest of the retrofitted building stock. The structure of the financial incentives and the definition of eligible costs are the same in the SLED moderate and ambitious scenarios.

HOW BIG ARE THE ASSOCIATED FINAL ENERGY SAVINGS AND CO_2 EMISSIONS REDUCTIONS?

According to the SLED moderate scenario, final energy consumption for thermal energy services will decrease to 2.3 billion kWh, or 15 percent lower than its business-as-usual level, in 2030. The associated CO_2

emissions would be 23 percent lower than their business-as-usual level. The scenario would lead to a 14 percent reduction in the business-as-usual wood consumption and a 19 percent reduction in the business-as-usual electricity consumption. Almost 72 percent of final energy savings will originate from small buildings located in climate zones 1 and 3, which were built in 1946–2015 and which are still remaining in 2070. The biggest energy savings would be associated with space heating.

According to the SLED ambitious scenario, final energy consumption for thermal energy services will decrease to 2.1 billion kWh, or 23 percent lower than its business-as-usual level, in 2030. The associated CO_2 emissions would be 46 percent lower than their business-as-usual level in 2030. The scenario would allow a 23 percent reduction in the business-as-usual wood consumption, and a 46 percent reduction in the business-as-usual electricity consumption. Almost 60 percent of the final energy savings would originate from small buildings located in climate zones 1 and 3, which were built in 1971–2015 and which are still remaining in 2050. The biggest energy savings would be associated with space heating.

HOW MUCH MIGHT SUCH EFFORTS COST THE GOVERNMENT AND OTHER ACTORS?

In the SLED moderate scenario, 314,000 m^2, or 1.6 percent, of the total building floor area is retrofitted per year in 2015–2030. This transformation requires significant investments, which should be distributed among different actors.

The total investment costs are EUR 692 million in 2015–2030, or EUR 46 million per year. The largest investments are required in buildings constructed in 1971–1990 and 2001–2015 (if building categories are analysed by decade). When the costs of the reference scenario are deducted from the costs of the SLED moderate scenario, the incremental costs of the SLED moderate scenario are EUR 285 million over 2015–2030, or EUR 19 million per year.

Assuming a discount rate of 4 percent, the annualised incremental costs of the SLED moderate scenario in 2015–2030 are EUR 1.9/m^2. Saved energy costs are EUR 3.6 per m^2 of new or retrofitted floor area on average over this period. This means that the investments in the SLED moderate scenario are profitable. It is important to note that the saved energy costs are higher than the annualised investment costs for the scenario as a whole at country level, but not for all building categories. For a few building categories, saved energy costs are lower than the annualised incremental investment costs, thus for them the incremental investments do not pay back. Raising the discount rate higher than 10 percent would make the SLED moderate scenario unattractive if only the saved energy costs are counted as scenario benefits. The analysis is carried out assuming a likely increase in energy prices.

The eligible investments in building retrofits that investors would have to borrow are EUR 183 million over 2015–2030, or EUR 12 million per year. Assuming a market loan interest rate of 10 percent, a subsidised interest rate of 0 percent, and a loan term of 10 years, the government would provide EUR 84 million to commercial banks as compensation for lowering the interest rate. Grants would cost the government EUR 89 million over 2015–2030, or EUR 6 million per year.

In the SLED ambitious scenario, 425,000 m^2, or 2.4 percent of the total building floor area, are retrofitted per year in 2015–2030. In addition, all new floor area — that is, 250,000 m^2 per year — is included in the scenario. The total investment costs are EUR 1.2 million over 2015–2030 or EUR 80 million per year. The incremental investment costs of the SLED ambitious scenario for building retrofits are EUR 796 million over 2015–2030, or EUR 53 million per year. The incremental investment costs of the SLED ambitious scenario into new, more efficient buildings are EUR 230 million in 2015–2030, or EUR 15 million per year.

Assuming the same discount rate, the annualised incremental costs of the SLED ambitious scenario over 2015–2030 are EUR 5.4/m^2. Saved energy costs are EUR 5.5/m^2 of new or retrofitted floor area over this period. This means that investments into the SLED ambitious scenario will pay back, although raising the discount rate higher would make them unattractive if only the saved energy costs are counted as scenario benefits. Similar to the SLED moderate scenario, the saved energy costs are higher than the annualised investment costs for the SLED ambitious scenario as a whole at country level, but not for all building categories.

The eligible investments in building retrofitting that investors would need to borrow are EUR 481 million over 2015–2030, or EUR 30 million per year. Eligible investments in more efficient construction that would need to be borrowed are EUR 97 million over 2016–2022, or EUR 6.5 million per year. Given the same assumptions as in the SLED moderate scenario, the government would provide to commercial banks EUR 204 million as compensation for lowering the interest rate for building retrofitting, and EUR 64 million for lowering the interest rate for building construction. Grants would cost the government EUR 179 million over 2015–2030, or EUR 11 million per year. In addition, investors would bear EUR 56 million in incremental investment costs per year as compared to the business-as-usual practice in order to comply with the building code to be adopted in 2022.

I. Introduction

Background

Following a steep decline in the 1990s, Montenegro experienced economic growth reaching 10.9 percent per year in 2007 (World Bank online). In the years following the global financial crisis, the economy went into recession. In order to recover and maintain high rates of economic growth, on the one hand Montenegro needs access to a long-term, secure, affordable and sustainable energy supply. On the other hand, the country needs to use its domestic energy resources, or purchased energy, in the most efficient and rational way.

Energy demand in the residential building sector represents a particular challenge. In 2010, the sector's final energy consumption was 23 percent of the national total (Ministry of Economy 2013b). Furthermore, the sector consumed around 37 percent of the electricity available for final consumption (*ibid*.). The quality of energy services delivered to residential buildings is far lower than is usual in the EU. Most notably, Montenegrin dwellings are heated partially only for a few hours a day. The continued use of outdated wood stoves results in high levels of indoor air pollution and therefore high rates of respiratory disease (Legro, Novikova and Olshanskaya 2014). Cutting down Montenegrin forests for household energy services leads to numerous environmental problems such as deforestation, biodiversity loss, air pollution and soil degradation (*ibid*). If no new forests are planted, there is no compensation for the greenhouse gas emissions released when burning this biomass.

Montenegro is a contracting party to the Energy Community Treaty and is thus obliged to introduce EU energy efficiency legislation. As of April 2015, the country had transposed the following EU energy efficiency directives into its national legislation: Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services (ESD); Directive 2002/91/EC on the Energy Performance of Buildings (EPBD) and its recast 2010/31/EU; Directive 2012/27/EU, the Energy Efficiency Directive (EED); as well as Directive 92/75/EEC on the Labelling of Household Appliances. Many by-laws of the listed directives, as well as the Labelling Directive (2010/30/EU), have still to be adopted. In accordance with the ESD, the country has to meet an energy-saving target equal to 9 percent of total energy sales in 2018 as compared to 2010. Achieving this target requires more ambitious policy efforts and larger investments in demand-side energy efficiency than are being made at present.

Alignment with EU energy efficiency legislation supports the measures required under the United Nations Framework Convention on Climate Change (UNFCCC). Examples include nationally appropriate mitigation actions (NAMAs), where developing countries are invited to contribute voluntary actions that help create low-carbon development strategies with the aim of promoting mitigation efforts; and intended nationally determined contributions (INDCs). Such measures require the introduction of a wide range of energy efficiency and low-carbon policies.

Even though there are many opportunities for energy efficiency improvement in the residential building sector, the policy mix in Montenegro to address these opportunities could be significantly improved. Designing an intelligent policy package is not easy, however, because energy efficiency potential is spread among different types of buildings and fragmented among end users. There is a lack of understanding of how to structure the building sector for policy making, how much potential there is for energy saving and CO_2 emissions reductions, where this potential is located, and how much it would cost to realise.

Aims and structure of the present publication

This book aims to address the gap in knowledge outlined above and to provide the necessary information to assist the evidence-based design of energy efficiency and climate mitigation policies in Montenegro targeting the residential building sector.

The book comprises two parts. In the first part, the following questions are addressed:

- How can existing residential buildings in Montenegro be classified according to their age and type? What are the representative building types in the Montenegrin residential building stock? How many buildings are there, and how many dwellings are there in those buildings, according to such a building typology?
- What are the energy demand, the delivered energy by energy source, primary energy consumption and CO_2 emissions in relation to space heating, water heating and space cooling for each representative building type?

- What are the possible retrofitting options and packages of options by representative building type? What are the investment costs per retrofitting measure and per building by representative building type?

The second part addresses the following questions:

- What are the future trends in energy consumption and CO_2 emissions in the residential building sector in Montenegro? What are the key influencing factors? What are the priority sector segments for policy making?
- What policy packages are possible, and what level of policy efforts are required in order to make residential buildings low energy and low carbon in the medium- and long-term future? How big are the associated energy savings and CO_2 emissions reductions? How much might such efforts cost the government and other actors?

PART 1

The typology of residential buildings, possible retrofitting packages and associated investment costs

II. Building typology of existing buildings

The building typology was created with the help of Montenegrin experts, based on the latest (2011) census data. We used openly available data from the statistical office Monstat. In our work we also used the preliminary results of Milica Jovanović Popović, Dušan Ignjatović and their colleagues on the building typology in Serbia, described in Jovanović Popović et al. (2013).

The definition of building types is based on the building type matrix for Serbia (Jovanović Popović et al. 2013). After analysing the Serbian matrix, Montenegrin experts recommended adapting the Serbian building types because of the many similar elements originating from the countries' common construction history. Regarding building structures and geometry, the Serbian matrix could be adopted in its entirety, although it was simplified by omitting and merging some building types. However, different building service systems and climatic conditions had to be incorporated into the typology assessment. One main difference between the two countries is that in Serbia, unlike Montenegro, gas and district heating are widely used. In Montenegro, electricity and wood are the most typical energy sources used for heating and hot water production.

As the census was not designed specifically to obtain data for an energy-related evaluation of the building stock, some data were not available at the required level of detail. Estimations were necessary in order to extrapolate data to the existing building stock.

We established 15 categories in the building typology based on the following considerations:

- Building type. The statistics distinguish between detached houses, semi-detached houses, row (terraced) houses and apartment buildings.
- Construction period. Buildings are classified into five construction periods: buildings constructed before 1945; between 1946 and 1970; between 1971 and 1990; between 1991 and 2000; and between 2001 and 2011.
- Building size. Data were available for the number of dwellings in the building: one or two dwellings; three to nine dwellings; and five or more dwellings.

Further aspects were also analysed, but as statistical data were not available per building type, these aspects were not incorporated directly into the matrix:

- Climate zone. All data were given at national level and for each prefecture.
- Construction material. Limited data were available.
- Heating system and energy source. National data were available.

The building typology for Montenegro is shown in Table 1.

Statistical data on the building stock

The total number of residential buildings in Montenegro was 171,676 according to the 2011 census for a population of 620,029 (64 percent of the population live in urban areas and 36 percent in rural areas). The number of dwellings was 315,670, of which only 188,376 were inhabited.

We classified the building stock into 15 building types. Figures 1 and 2 show the number of buildings and the number of dwellings in each building type. Detached and other houses with up to two flats, built between 1971 and 1990 (type A3), represent the biggest group with 60,667 buildings. Besides the dominance of small buildings, large apartment buildings (with 10 or more dwellings) built in 1971–1990 and after 2000 are also significant in terms of the number of dwellings.

Figure 1 also shows the number of residential buildings with an unknown construction date. Used and unused buildings are not separated in the figure, because such statistics are not available on the basis of building type. Only estimations are possible.

RESIDENTIAL BUILDINGS BY BUILDING TYPE

Detached houses represent the highest share in the building stock, with 83.7 percent of all buildings. Although apartment buildings represent only 3.7 percent of the stock, these multi-storey buildings contain a large number of dwellings, representing about 35 percent of all dwellings. Semi-detached houses have a share of 9.4 percent, while row (terraced) houses are less significant (Figures 3 and 4).

RESIDENTIAL BUILDINGS BY CONSTRUCTION PERIOD

Only 6 percent of the existing building stock was built before 1945 (Figures 5 and 6). Between 1971 and 1990, there was an upswing in the construction sector. Large multi-family apartment buildings in particular were constructed using prefabrication technology. This period saw the construction of 38 percent of buildings and 38 percent of dwellings (Figure 7). In the 1990s we can observe a decline in

Table 1 Montenegrin residential building typology (Jovanović Popović et al. 2013)

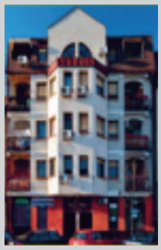
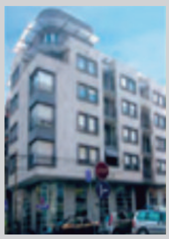
		Single-family houses	Multi-family housing	Multi-family housing
		A	B	C
		1. Family house 2. With two dwellings (one above the other) 3. Semi-detached house	4. With three to nine dwellings	5. With 10 or more dwellings
1	1919–1945			
2	1946–1970			
3	1971–1990			
4	1991–2000			
5	2001–2011			

Figure 1 **Number of residential buildings and dwellings by building type and construction period** (Monstat 2011)

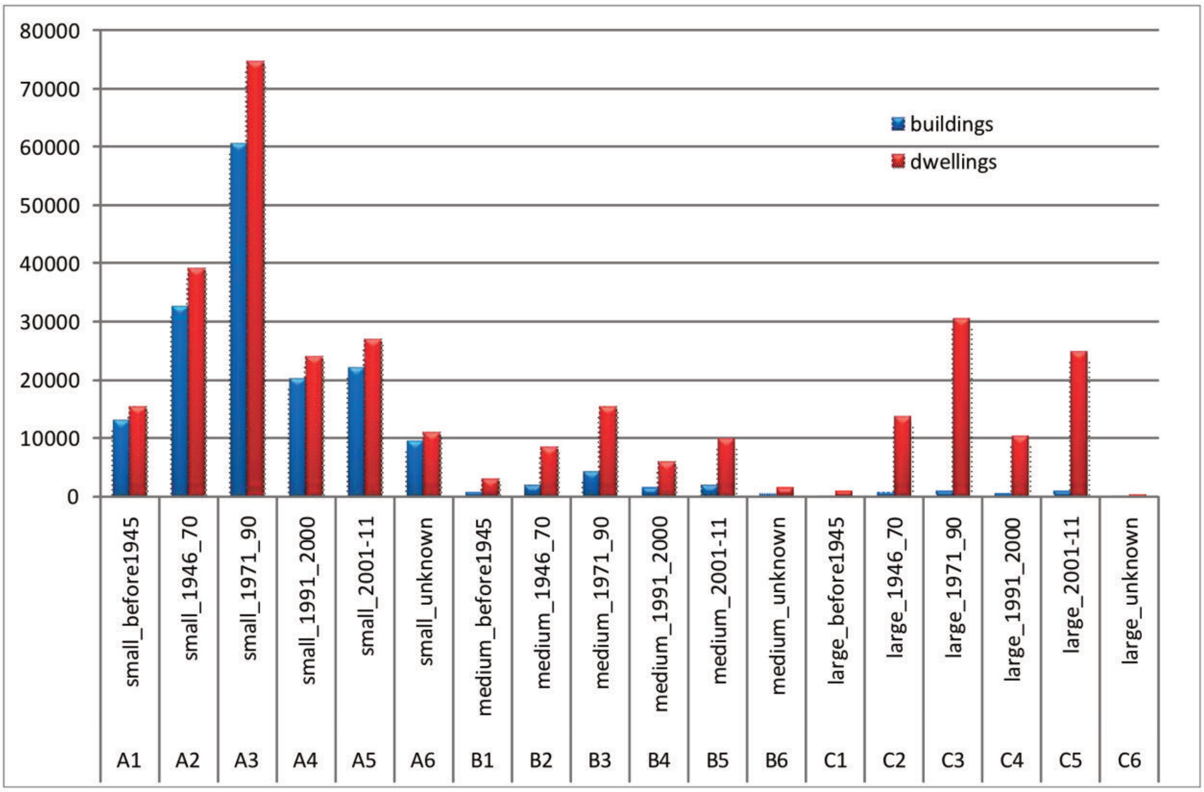
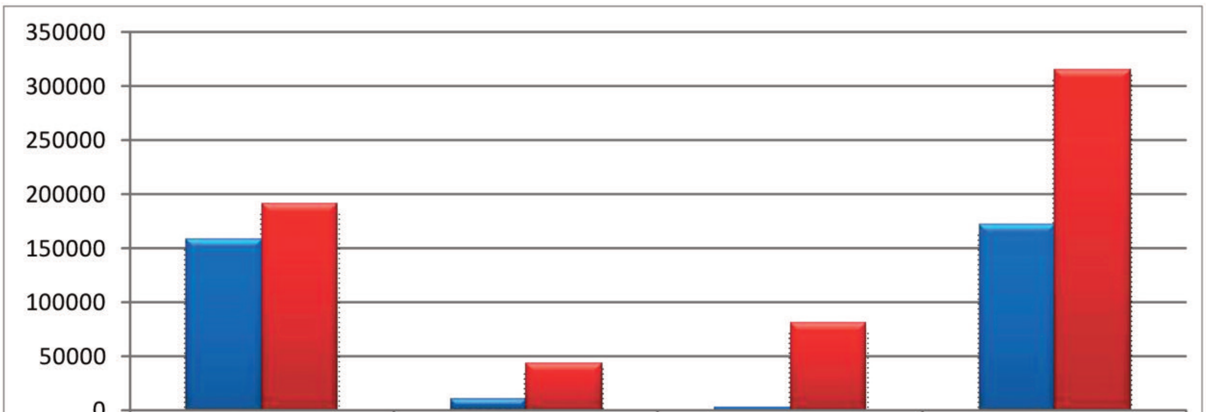


Figure 2 **Number of residential buildings and dwellings by building type** (Monstat 2011)



	small (1-2 flats)	medium (3-9 flats)	large (10- flats)	total
buildings	158176	10571	2929	171676
dwellings	191240	43786	80644	315670

Figure 3 Share of residential buildings by building type (Monstat 2011)

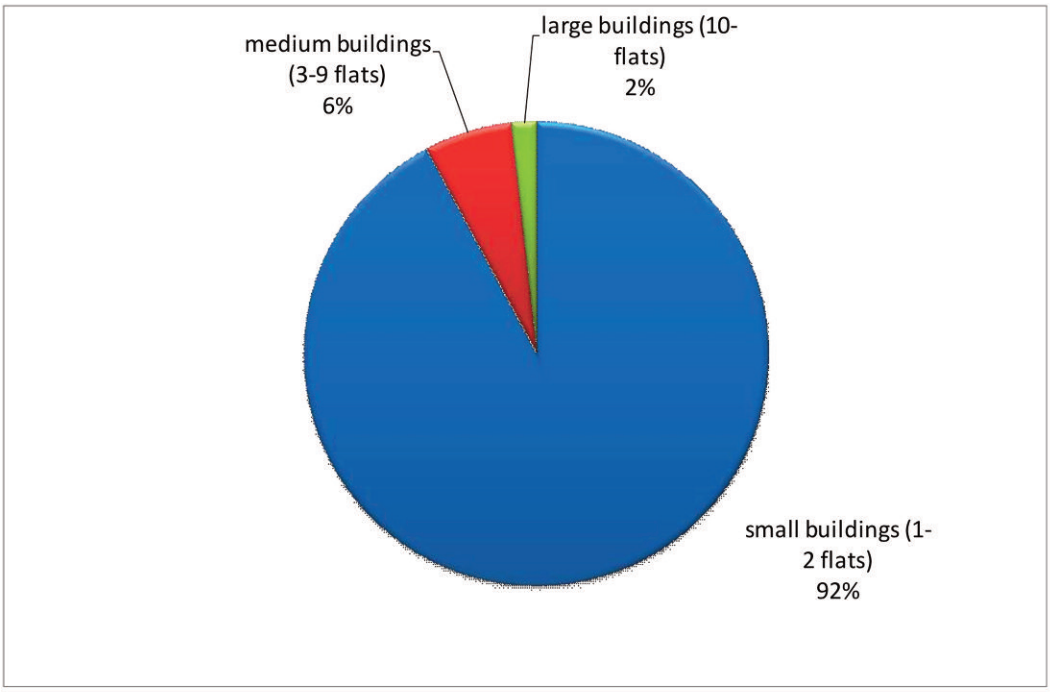
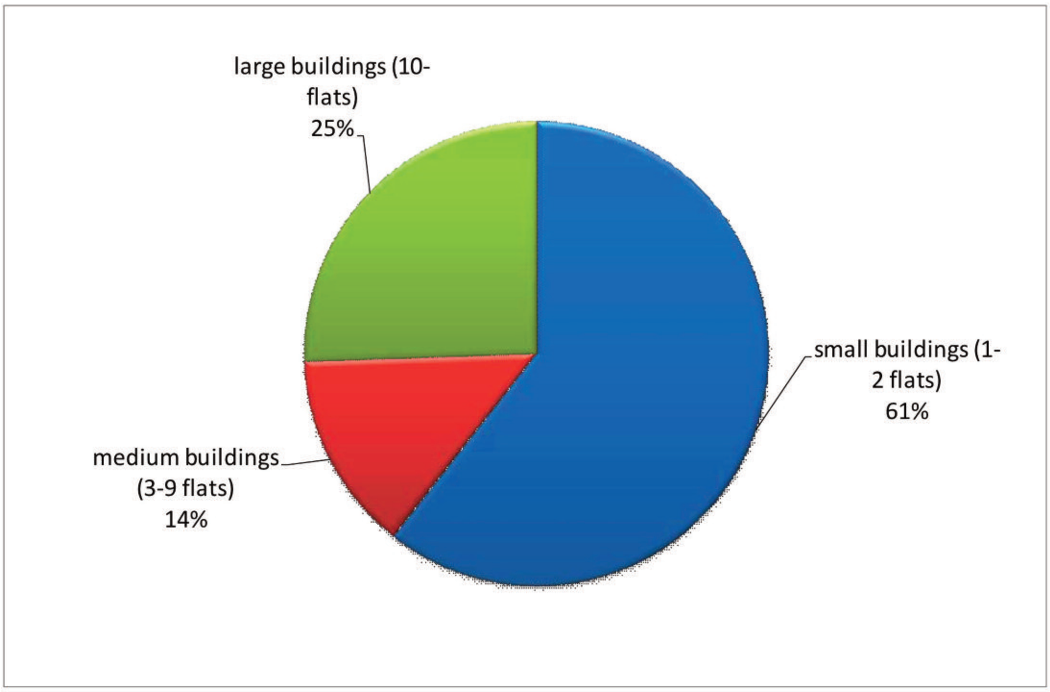


Figure 4 Share of dwellings in residential buildings by building type (Monstat 2011)



the construction sector, with an increase after 2001, particularly in multi-apartment buildings. In the case of 6 percent of the building stock, the construction period is not known.

SMALL BUILDINGS (ONE OR TWO DWELLINGS)

Most houses with one or two dwellings were constructed after 1945, with a peak between 1971 and 1990 when about 38 percent of existing detached houses were constructed (Figures 8 and 9). After this period the construction rate decreased slightly (26 percent of these houses were built after 1990).

MEDIUM-SIZED BUILDINGS (THREE TO NINE DWELLINGS)

The construction rate of medium-sized buildings is more balanced. The most intensive periods were 1971–1990 and 2001–2011 (Figures 10 and 11).

LARGE APARTMENT BUILDINGS (10 OR MORE DWELLINGS)

Only 2 percent of apartment buildings were constructed before 1945. The boom started after 1960, when a large number of prefabricated buildings were constructed in the communist era. The construction of apartment buildings slowed down after 1990, but the 2001–2011 period was the most productive (Figures 12 and 13).

Non-inhabited buildings and dwellings

There are no statistical data about the number of inhabited buildings, only about dwellings.

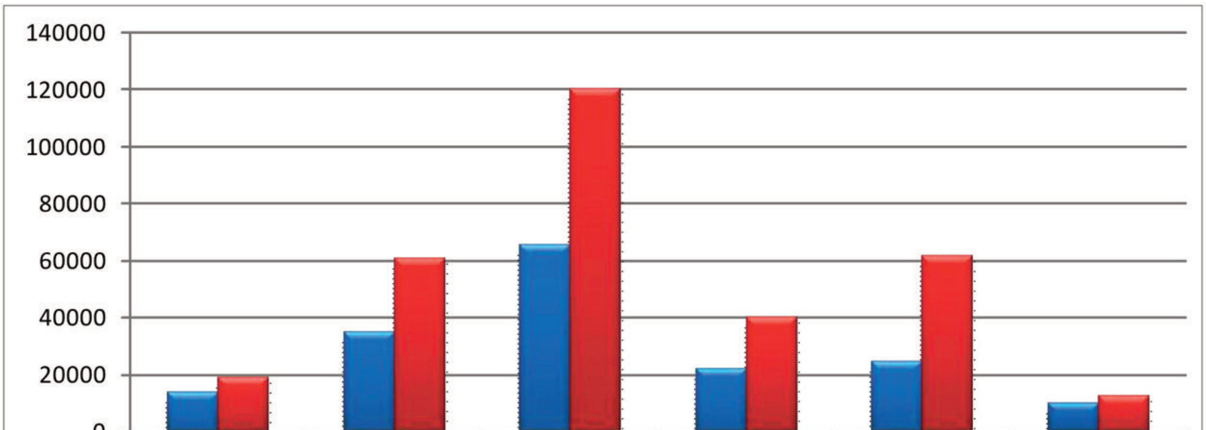
The high number of non-inhabited dwellings is remarkable. There are 58,978 dwellings that are vacant (temporarily vacant or non-inhabited), although the figure is even higher (120,838) if dwellings for seasonal use (61,860) are also included. Vacant or seasonally used dwellings accounted for 38.4 percent of dwellings in 2011 (Figure 14).

It is likely that many of the non-inhabited dwellings are located in partly inhabited buildings. However, this fact could not be taken into account in our calculations, where the share of non-inhabited buildings was considered equal to the share of non-inhabited dwellings. This approximation is certainly not accurate, although in terms of energy consumption no better assumption can be established based on the available data.

Climate zones

Montenegro is divided into three climate zones: zone 1 is the mildest, and the corresponding area is located along the coast; zone 2 is the moderate zone;

Figure 5 **Number of residential buildings by construction period** (Monstat 2011)



	before 1945	1946-70	1971-90	1991-2000	2001-11	unknown
buildings	13878	34937	65861	22143	24865	9992
dwellings	19303	61112	120617	40254	61667	12717

Figure 6 Share of residential buildings by construction period (Monstat 2011)

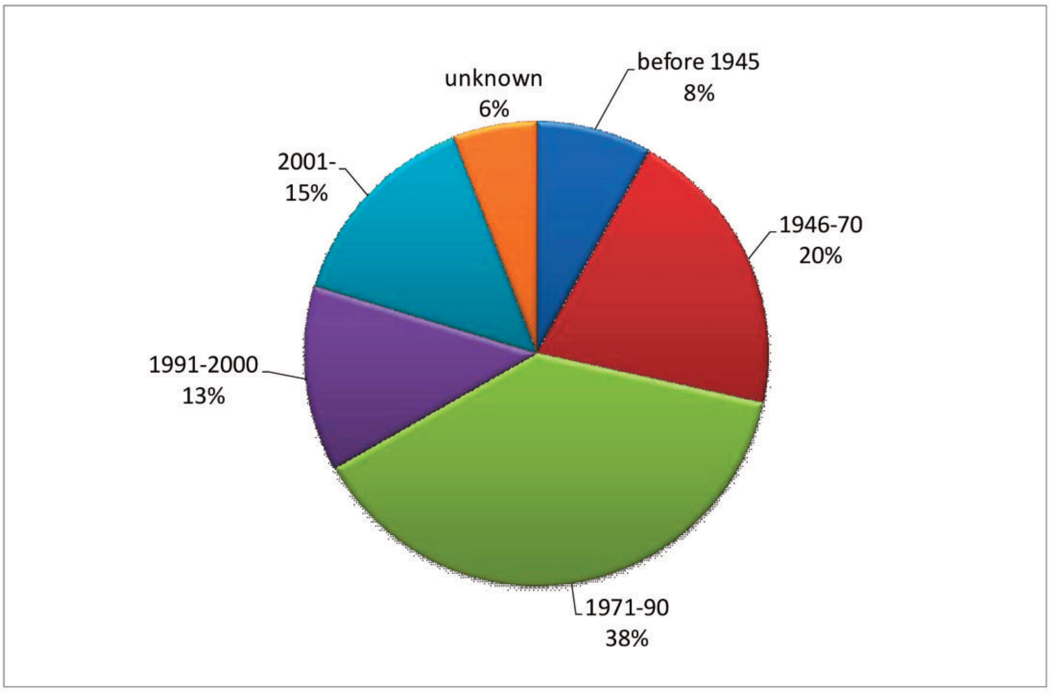


Figure 7 Share of dwellings in residential buildings by construction period (Monstat 2011)

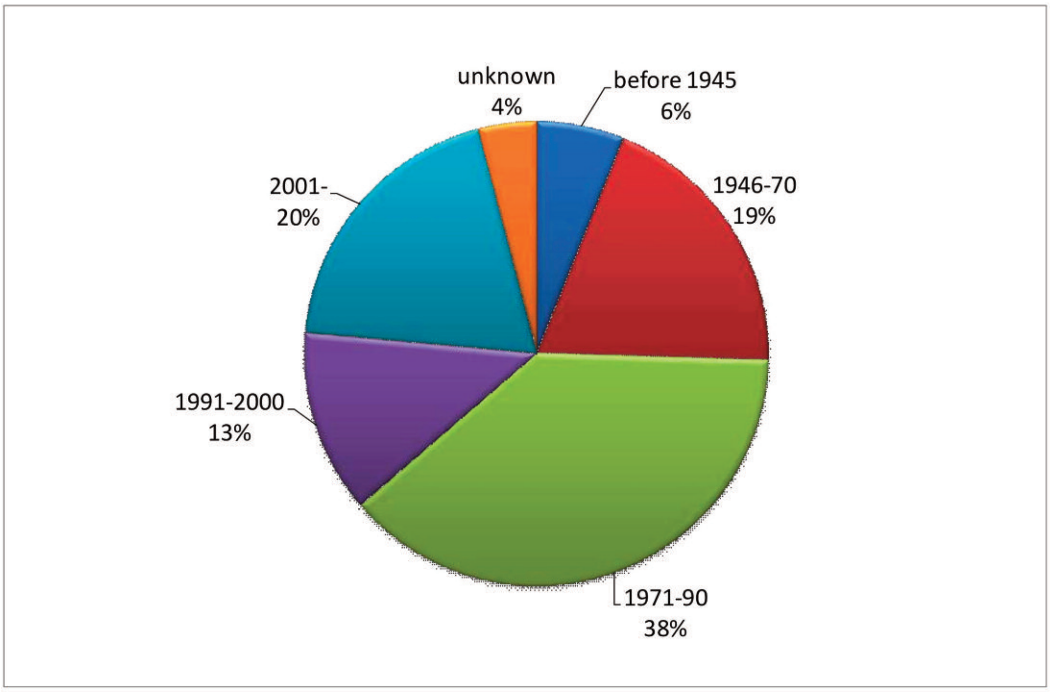
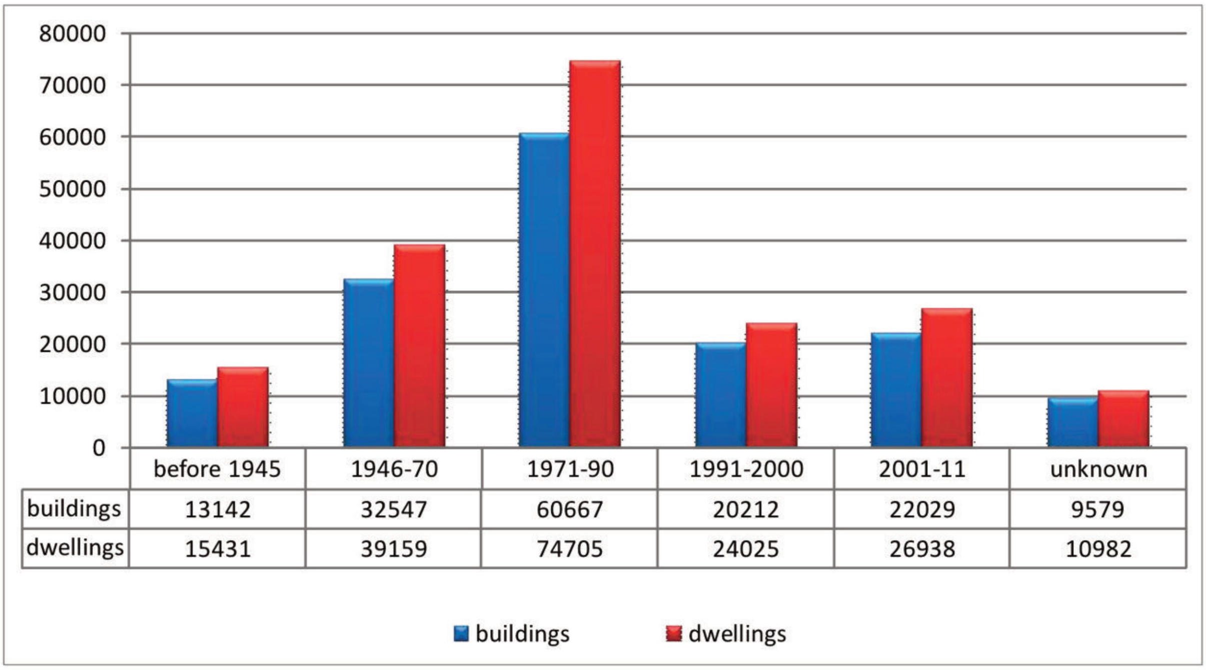


Figure 8 Number of small houses (one or two dwellings) by construction period (Monstat 2011)



	before 1945	1946-70	1971-90	1991-2000	2001-11	unknown
buildings	13142	32547	60667	20212	22029	9579
dwellings	15431	39159	74705	24025	26938	10982

Figure 9 Share of small houses (one or two dwellings) by construction period (Monstat 2011)

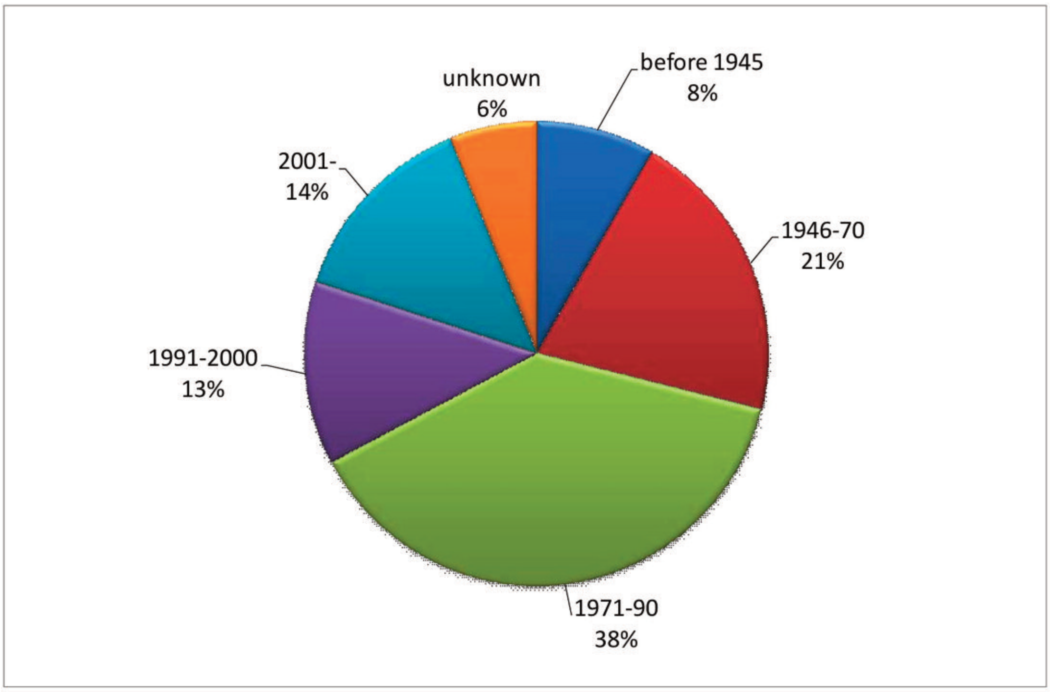
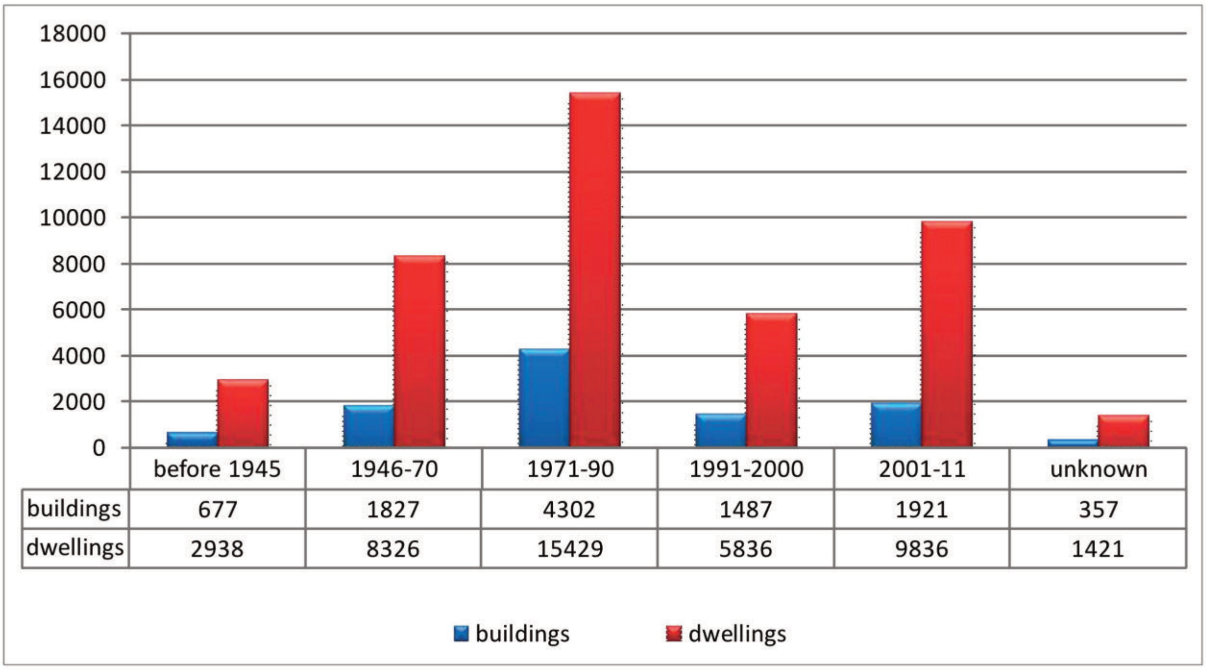


Figure 10 Number of medium-sized buildings (three to nine dwellings) and dwellings in these buildings by construction period (dwellings estimated only) (Monstat 2011)



	before 1945	1946-70	1971-90	1991-2000	2001-11	unknown
buildings	677	1827	4302	1487	1921	357
dwellings	2938	8326	15429	5836	9836	1421

Figure 11 Share of medium-sized buildings (three to nine dwellings) by construction period (Monstat 2011)

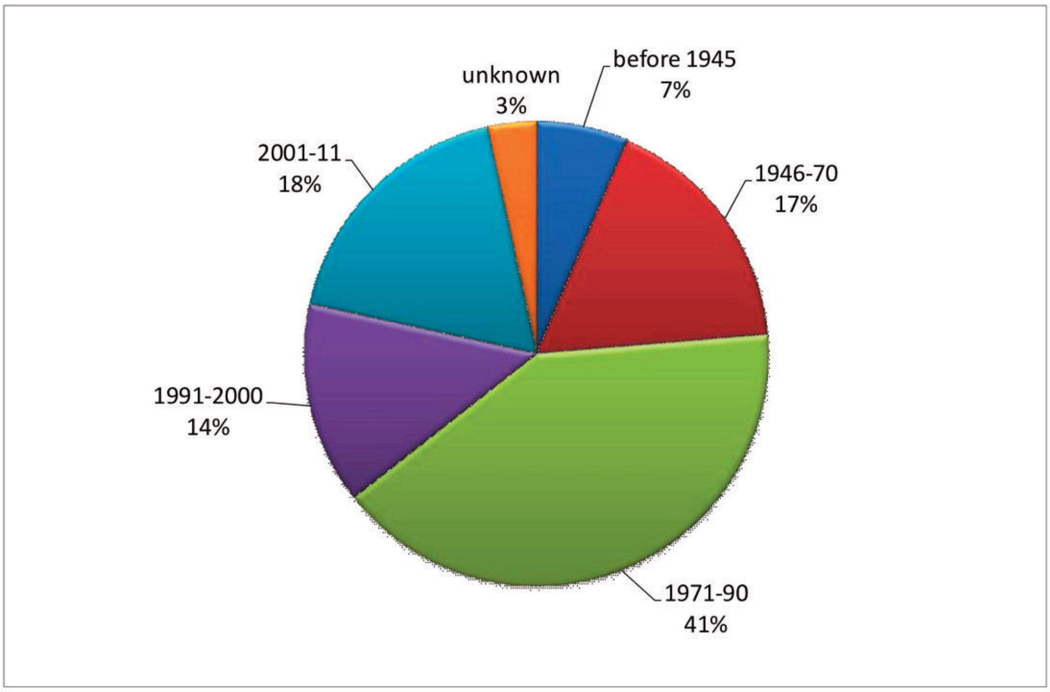
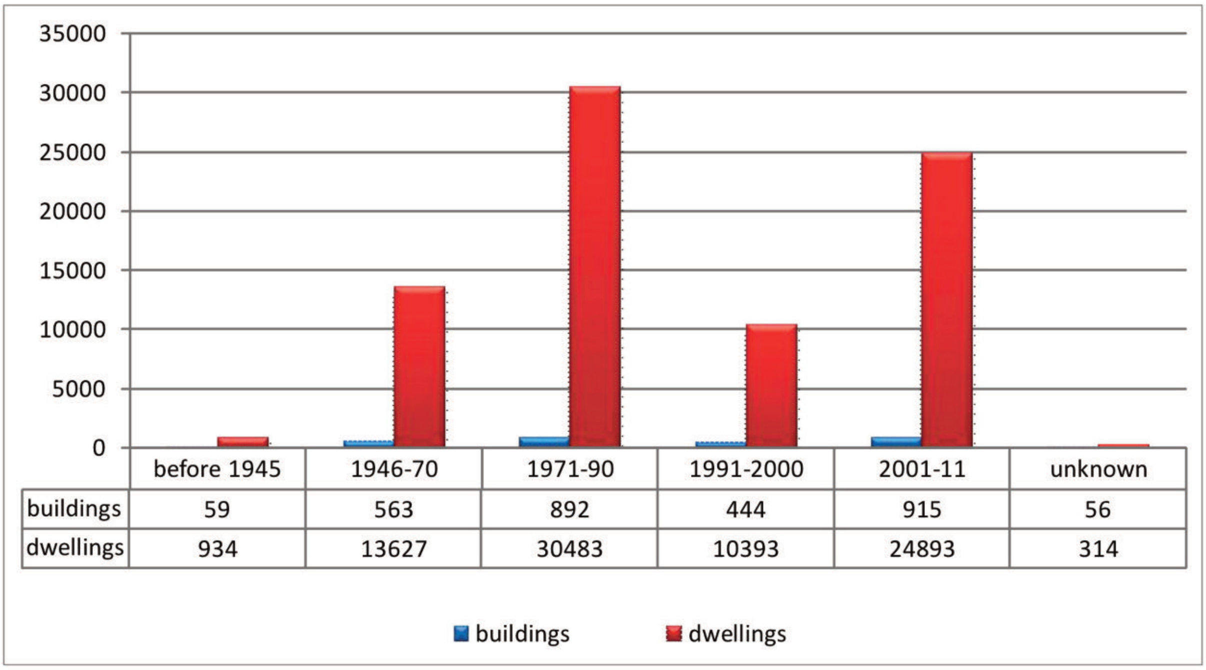


Figure 12 Number of large apartment buildings and dwellings in these buildings by construction period (Monstat 2011)



	before 1945	1946-70	1971-90	1991-2000	2001-11	unknown
buildings	59	563	892	444	915	56
dwellings	934	13627	30483	10393	24893	314

Figure 13 Share of large apartment buildings by construction period (Monstat 2011)

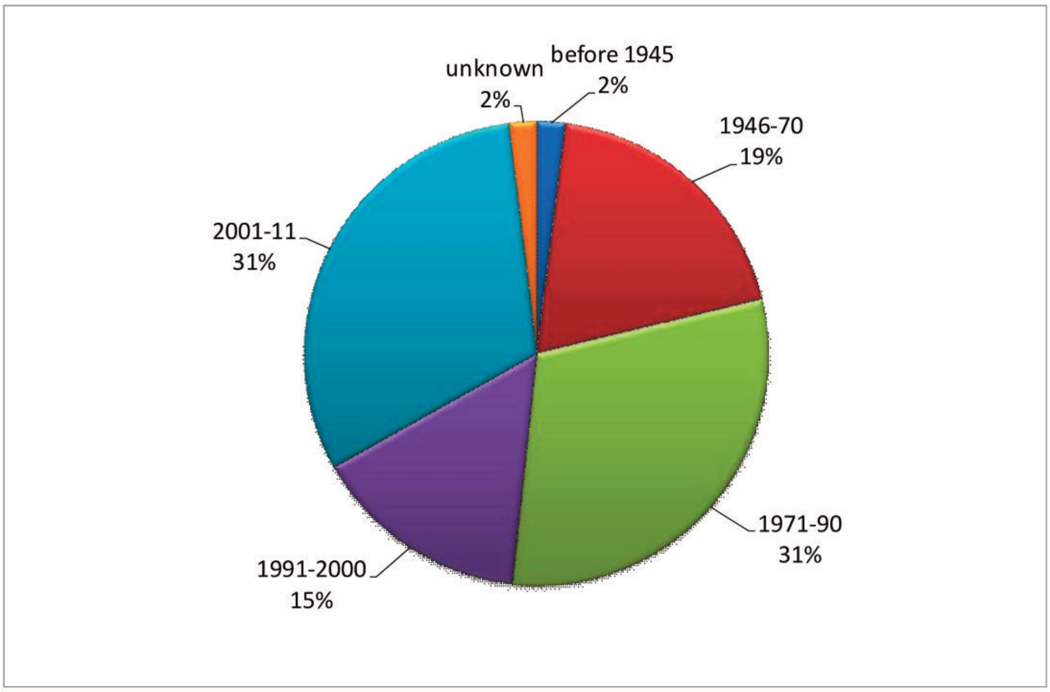
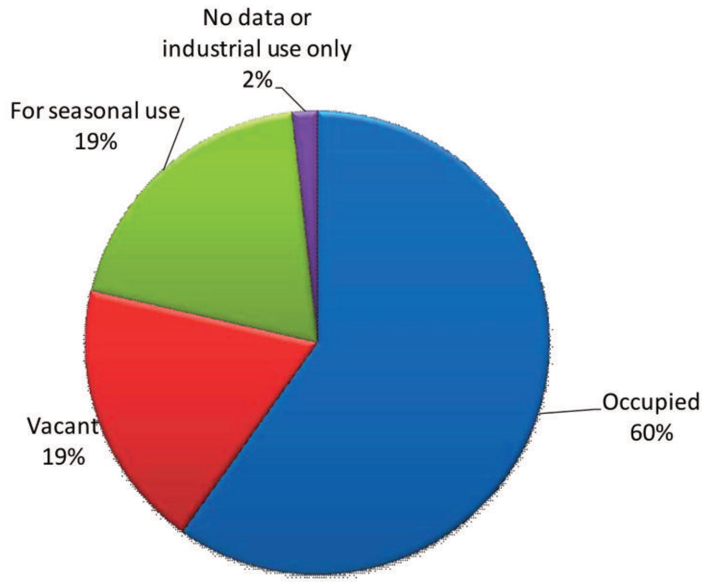


Figure 14 Share of dwellings by occupancy (Monstat 2011)



and zone 3 is the coldest, in the mountainous area (Figure 15).

There are no statistical data about the number of buildings per climate zone, only about the number of dwellings. However, there are statistics about the occupancy level per climate zone. About two-thirds of dwellings are located in climate zone 1, and about a quarter of dwellings are located in climate zone 3. The fewest buildings, about 11 percent of the stock, are located in climate zone 2 (Figure 16).

Trends

The total number of residential buildings in Montenegro was 171,676 according to the 2011 census, for a population of 620,029 (64 percent of the population live in urban areas and 36 percent in rural areas). The share of the urban population in Montenegro is continuously increasing (from 58.54 percent in 2000 to 63.83 percent in 2014).

Between 4,000 and 5,000 new dwellings are built each year, the majority (70 to 80 percent) being detached houses (see Figure 17). The average floor area of a dwelling was 65 m^2 in multi-residential buildings and 74 m^2 in private houses in the period 2008–2013 (Figures 18 and 19).

Demolition rates are low. Between 2011 and 2013 only 13 to 20 buildings were demolished annually (Figure 20). The low number can be explained by the costs of demolition: it is easier to abandon a building than demolish it. Most of the buildings were demolished to make way for new constructions.

Figure 15 **Share of dwellings by climate zone** (Monstat 2011)

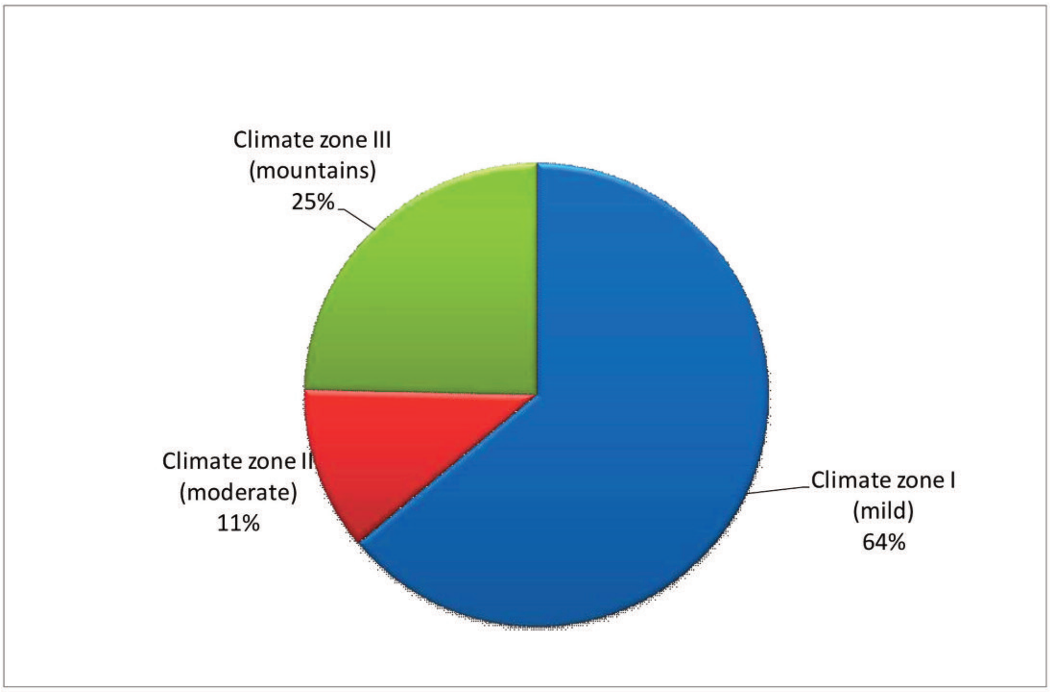
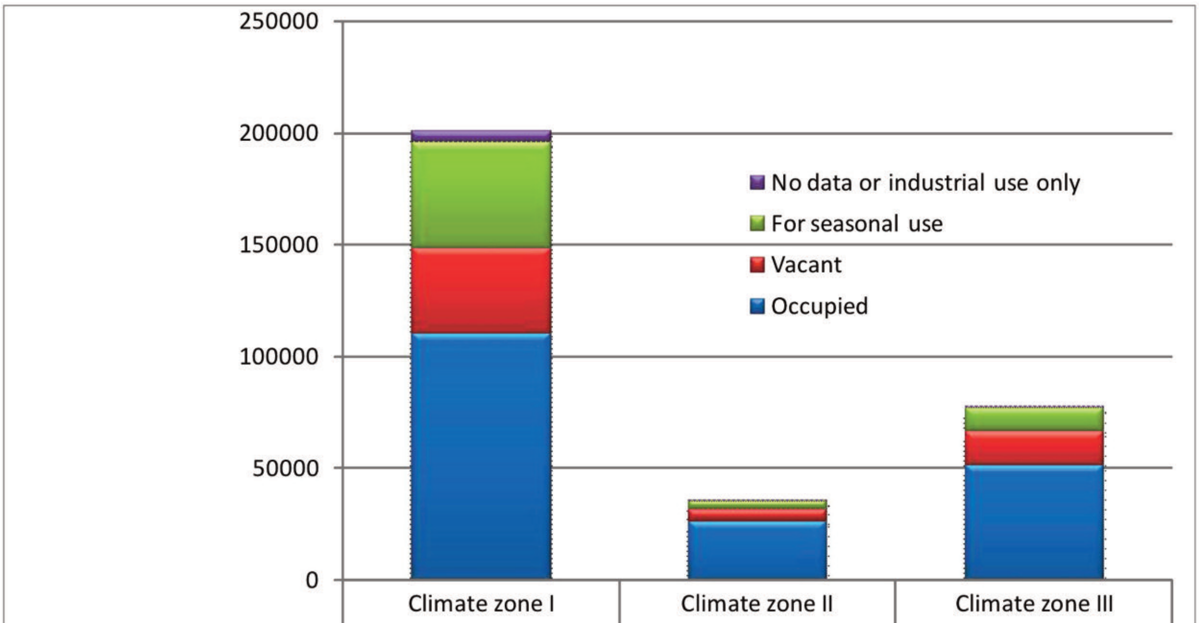
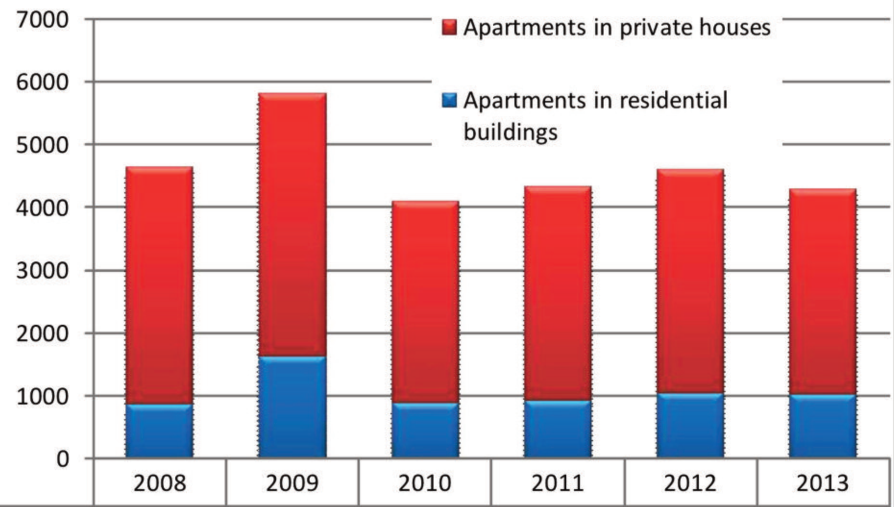


Figure 16 **Number of dwellings by climate zone and occupancy** (Monstat 2011)



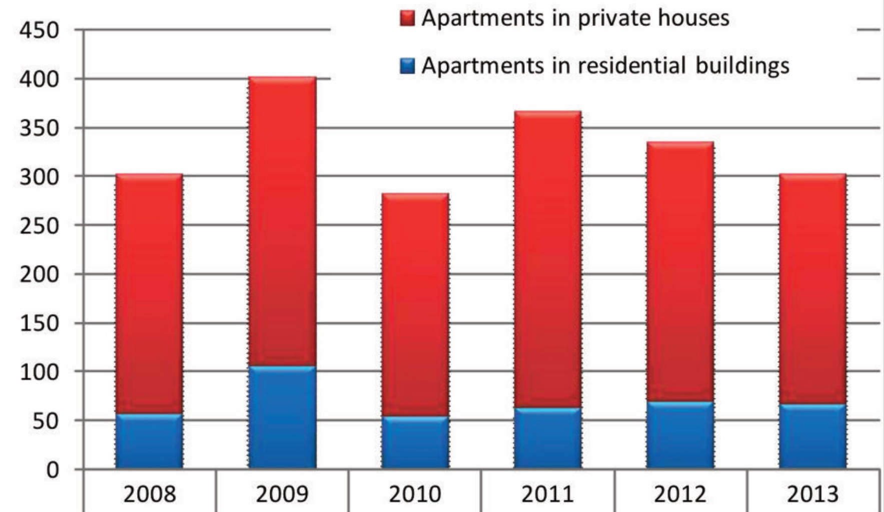
	Climate zone I	Climate zone II	Climate zone III
No data or industrial use only	5067	154	269
For seasonal use	47345	3986	10529
Vacant	38660	5068	15250
Occupied	110200	26661	51515

Figure 17 New constructions: Number of finished dwellings (Monstat 2012)



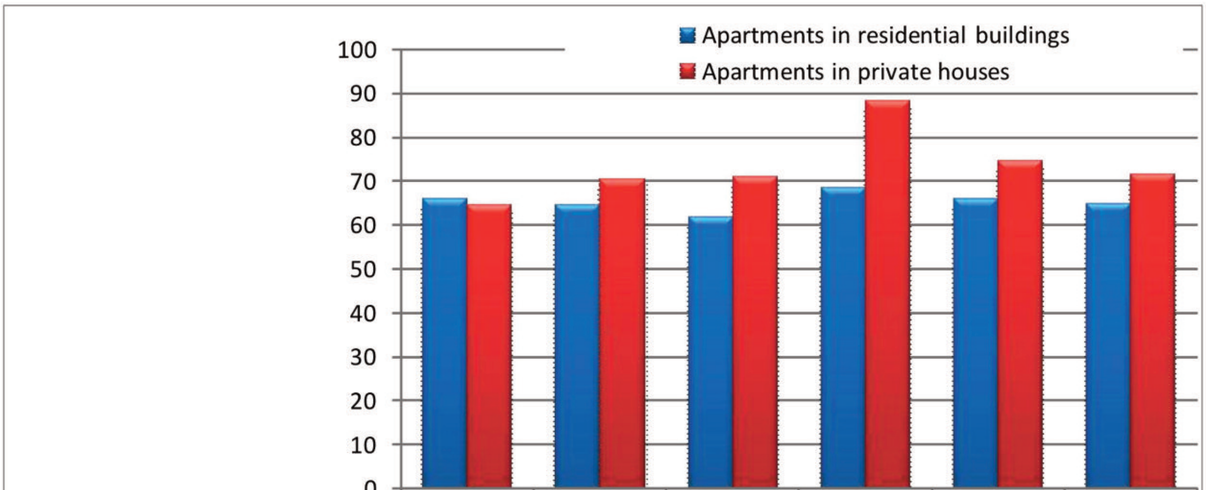
	2008	2009	2010	2011	2012	2013
Apartments in private houses	3773	4188	3203	3412	3540	3276
Apartments in residential buildings	877	1637	890	931	1059	1029

Figure 18 New constructions: Total floor area of finished dwellings (1,000 m²/year) (Monstat 2012)



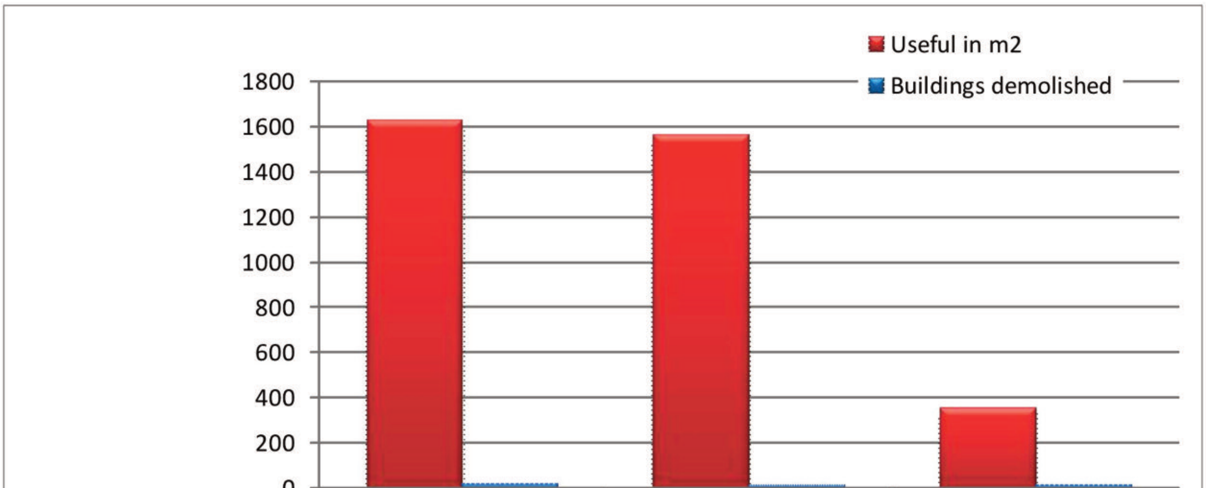
	2008	2009	2010	2011	2012	2013
Apartments in private houses	244	296	228	302	265	235
Apartments in residential buildings	58	106	55	64	70	67

Figure 19 New constructions: Average floor area of finished dwellings (m²) (Monstat 2012)



	2008	2009	2010	2011	2012	2013
Apartments in residential buildings	66	65	62	69	66	65
Apartments in private houses	65	71	71	89	75	72

Figure 20 Demolished buildings: Number (per year) and total floor area of demolished buildings (m²/year) (Monstat 2012)



	2011	2012	2013
Useful in m2	1628	1564	358
Buildings demolished	20	13	14

Further statistical data on building types

In order to adjust the building type model, specific statistical data were filtered on the basis of building type. To determine the main characteristics of the model, such building data were analysed as the size of the building, the number of rooms, the number of inhabitants, the typically used energy sources, the type of heating and the use of air conditioners. The results are based on the 2011 census data. These data were available only at a limited level — the only question related to heating, for example, was whether or not there was central heating. No data were available about the type of heating system. The processed statistical data are presented in Tables 2 to 4.

Theoretically, it is possible to classify the building types into further subgroups, taking into account the different characteristics described in the table. For instance, building type A1 is mostly heated by solid fuel, although electricity is also significant. Most of these buildings have no air-conditioning system, although many of them have cooling. However, taking into account all the frequent options in all variations, the number of subtypes would significantly increase, leading to a very complex model that would be difficult to handle. The number of variations was therefore limited as far as possible.

Table 2 **Statistical data per building type: Small buildings (one or two dwellings)** (Monstat 2011)

	1919–1945		1946–1970		1971–1990		1991–2000		2001–2011	
	A1		A2		A3		A4		A5	
	per building	per flat	per building	per flat	per building	per flat	per building	per flat	per building	per flat
Total number	13,142	15,431	32,547	39,159	60,667	74,705	20,212	24,025	22,029	26,938
Number of dwellings/buildings	1.2	-	1.2	-	1.2	-	1.2	-	1.2	-
Average year of construction	1925	-	1961	-	1981	-	1996	-	2006	-
Piped water installed	8,064*	9,468	24,295	29,963	55,133	68,300	18,718	22,351	20,562	25,254
Number of rooms	3.0	2.7	4.0	3.0	83.0	3.3	4.0	3.5	4	3.3
Average floor area	72	63	79	66	97*	78*	101	82	100	85
With central heating	294	327	1,485	1,657	4,556	5,087	1,894	2,045	2,053	2,310
Without central heating	8,757	10,090	25,507	30,625	45,727	55,518	14,229	16,528	14,633	17,477
Energy sources for heating										
Solid fuels	7,609	8,438	24,028	27,651	43,077	49,322	13,661	14,981	13,578	15,180
Liquid and gaseous fuels	60	74	128	165	335	434	152	177	162	202
Electricity	793	1,162	1,916	3,125	5,583	8,528	1,762	2,525	2,242	3,249
Solar energy	2	2	5	5	15	35	8	11	24	30
Other type of energy	6	6	35	45	30	33	56	60	23	29
Dwelling with no heating	297	387	292	495	665	1,236	245	433	339	606
With attic space	31	-	101	-	576	-	253	-	170	-
With cellar	8	-	45	-	70	-	14	-	13	-
Air conditioning										
Yes, from installation in building	-	-	4	9	49	108	65	66	60	76
Yes, from installation in dwelling	1,526	1,880	5,825	7,187	17,196	20,638	6,960	8,162	8,133	9,027
No	9,559	11,013	24,091	28,686	38,953	47,884	11,532	13,659	14,520	15,291
Average number of occupants	3	3	4	3	4	3	4	4	4	4

****estimated***

Table 3 Statistical data per building type: Medium-sized buildings (three to nine dwellings) (Monstat 2011)

	1919–1945		1946–1970		1971–1990		1991–2000		2001–2011	
	B1		B2		B3		B4		B5	
	per building	per flat	per building	per flat	per building	per flat	per building	per flat	per building	per flat
Total number	677	2,938	1,827	8,326	4,302	15,429	1,487	5,836	1,921	9,836
Number of dwellings/buildings	4.3	-	4.6	-	3.6	-	3.9	-	5.1	-
Average year of construction	1925	-	1961	-	1981	-	1996	-	2006	-
Piped water installed	655	2,727	1,797	8,067	4,288	15,169	1,486	5,763	1,914	9,721
Number of rooms	11	2.6	11	2.5	-	-	-	-	13	2.6
Average floor area	244	60	243	56	254	65	271	65	297	65
With central heating	4	49	78	363	256	828	76	322	90	426
Without central heating	509	1,923	1,708	6,978	3,630	11,098	1,107	3,708	1,190	5,282
Energy sources for heating										
Solid fuels	254	862	1,282	4,777	2,280	6,148	530	1,446	379	1,377
Liquid and gaseous fuels	5	21	7	48	16	98	6	28	10	49
Electricity	210	887	478	2,281	1,476	5,019	589	2,180	802	3,734
Solar energy	-	-	1	5	-	2	1	4	5	23
Other type of energy	-	-	1	9	1	13	4	3	-	-
Dwelling with no heating	22	89	17	143	109	471	45	190	49	289
With attic space	74	-	113	-	727	-	253	-	360	-
With cellar	1	-	16	-	35	-	9	-	5	-
Air conditioning										
Yes, from installation in building	2	8	1	5	26	70	27	101	44	221
Yes, from installation in dwelling	282	1,141	685	2,829	2,124	6,476	882	3,174	1,283	6,185
No	299	1,265	1,128	5,033	2,043	7,531	529	2,047	486	2,392
Average number of occupants	7	3	10	3	8	3	8	3	7	3

Energy sources used for heating

Data on the main energy sources are available for heating per building type. According to the 2011 census, the most common energy source was still solid fuel (84 percent, mainly wood), followed by electricity (20.8 percent) (Figure 21). Solar heating and other energy sources, such as gas and oil, were negligible. About 1.6 percent of the total household area was not heated.

There are significant differences between building types. In the case of small houses and older, medium-sized buildings, wood is dominant, while in the case of large buildings electricity is the dominant heat source (Figure 22).

Heating systems

Data on heating systems per building type are rather limited and do not include the types of devices, their efficiency, or even their age, which could be used to form an expert estimate of the mentioned parameters. The only available information regarding heating systems is the type of fuel used, the number of buildings using it (see above) and the shares of buildings with central heating and decentralised systems. It should be noted that, in the case of small buildings, it is difficult to interpret the difference between central and decentralised systems. It is possible that, in the census, the question was misinterpreted and that "central" was confused with "per dwelling". However, the share of

Table 4: **Statistical data per building type: Large buildings (10 or more dwellings)** (Monstat 2011)

	1919–1945		C1		1971–1990		C1		C1	
	C1		C1		C1		C1		C1	
	per building	per flat	per building	per flat	per building	per flat	per building	per flat	per building	per flat
Total number	59	934	563	13,627	892	30,483	444	10,393	915	24,893
Number of flats/buildings	15.8	-	24.2	-	34.2	-	23.4	-	27.2	-
Average year of construction	1923	-	1960	-	1981	-	1996	-	2006	-
Piped water installed	57	922	563	13,489	892	30,369	444	10,326	915	24,638
Number of rooms	23	1.5	59	2.4	82*	2.4*	56	2.4	66	2.4
Average floor area	487	40	1,178	50	2,054	59	1,229	51	1,481	56
With central heating	-	14	7	346	17	1,321	14	462	63	1,272
Without central heating	29	404	553	11,772	846	24,806	391	7,376	707	14,803
Energy sources for heating										
Solid fuels	14	183	272	4,114	261	6,284	44	1,007	56	852
Liquid and gaseous fuels	-	3	-	46	68	125	1	28	10	61
Electricity	12	160	289	7,726	596	18,870	351	6,485	682	14,241
Solar energy	-	-	-	-	-	2	-	3	3	20
Other type of energy	-	-	-	4	2	21	-	7	1	18
Dwelling with no heating	-	8	-	75	3	138	6	86	7	154
With attic space	11	-	155	-	226	-	151	-	265	-
With cellar	3	-	42	-	15	-	4	-	5	-
Air conditioning										
Yes, from installation in building	-	-	-	-	3	34	8	282	43	1,116
Yes, from installation in dwelling	40	643	292	6,716	567	16,835	317	6,476	751	18,329
No	16	248	269	5,834	316	11,014	118	2,751	107	2,847
Average number of dwellers	28	3	51	3	82	3	40	3	35	3

central heating systems in multi-apartment buildings is between 1 and 7 percent only (Figure 23), thus in the building model central systems can be ignored.

Regarding the devices used for heating, there are no data per dwelling or building type.

Domestic hot water production

Monstat does not provide any statistical data concerning sanitary hot water supply, although typically in Montenegrin households hot water is produced using an electric boiler (generally with a capacity of 80 litres and 2.5 kW electrical power).

Energy efficiency measures aimed at the production of sanitary hot water (such as the installation of solar water-heating systems) are easier to implement in single-family houses than in multi-family buildings, due to organisational issues in coordinating residents.

In certain building types, particularly in family houses built before 1970, there are no water pipes installed (Figure 24). However, this does not mean that no hot water is produced, since the water can be supplied from on-site wells. It can nevertheless be assumed that the energy demand for domestic hot water in these houses is significantly lower than in buildings with water pipes installed.

Figure 21 Share of household area per energy source used for heating (Monstat 2011)

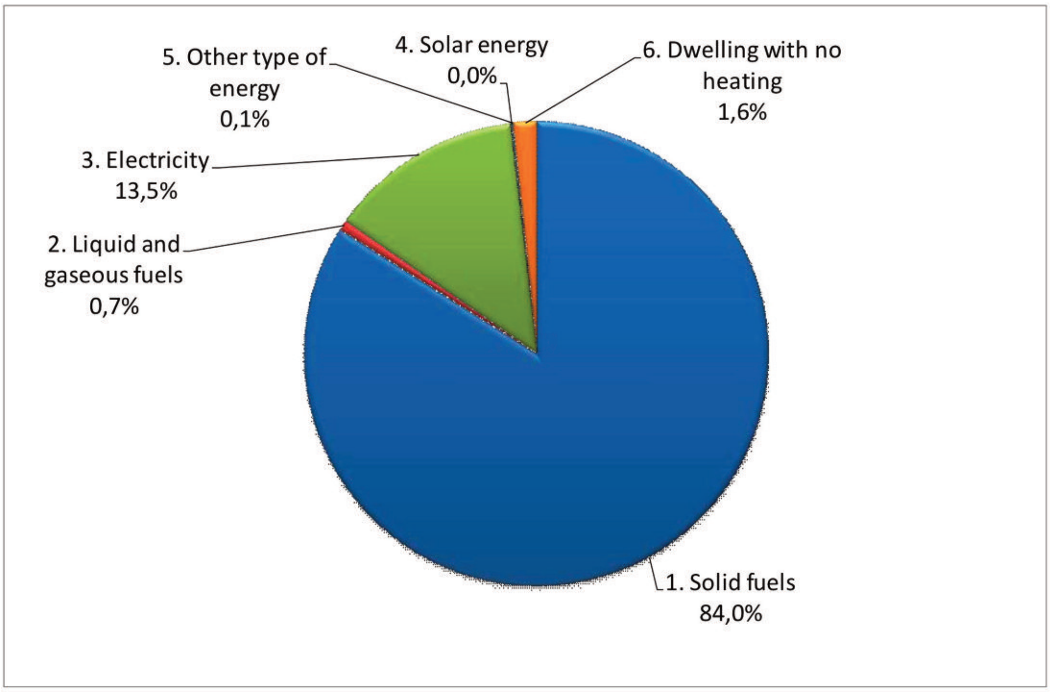
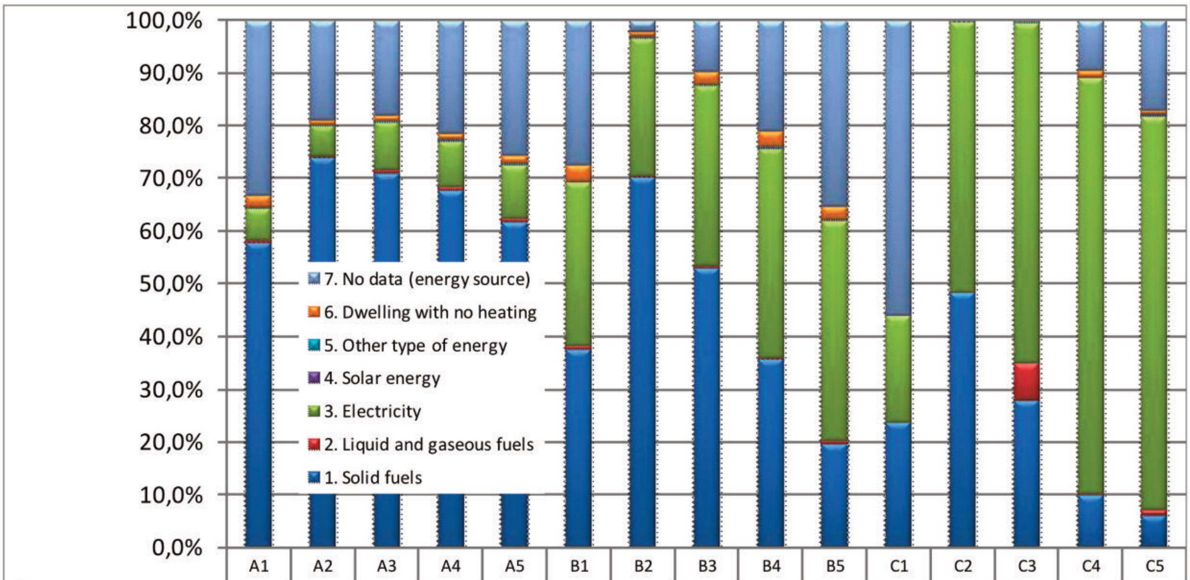
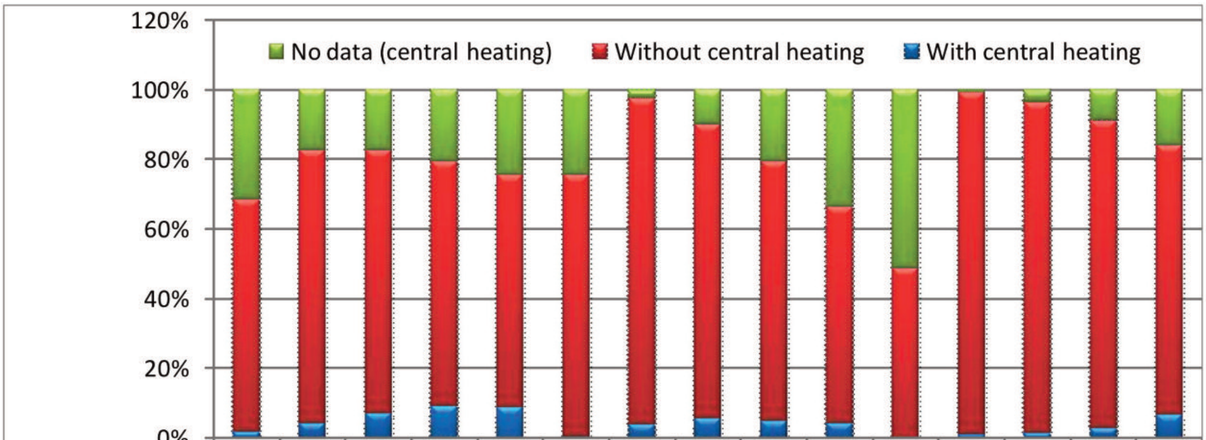


Figure 22 Share of energy sources used for heating per building type (Monstat 2011)



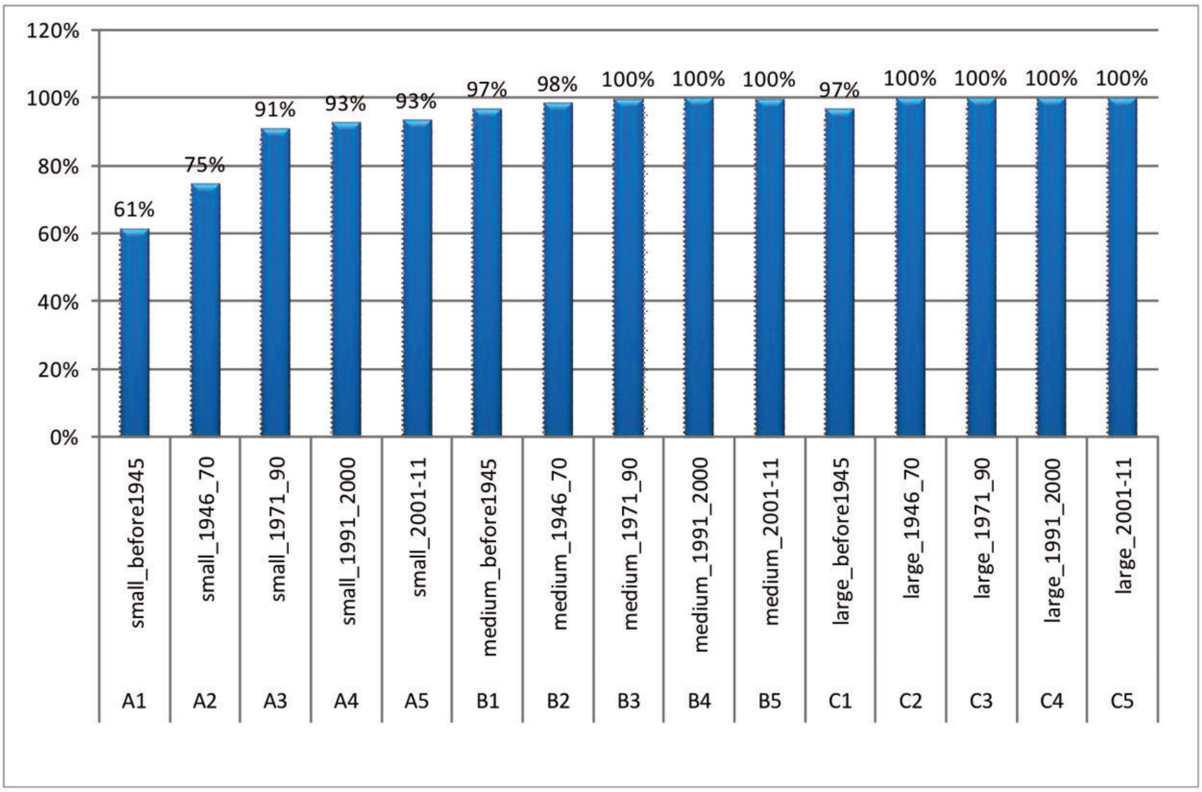
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
7. No data (energy source)	33,3%	18,9%	18,1%	21,4%	25,7%	27,5%	2,2%	9,8%	21,0%	35,2%	55,9%	0,4%	0,0%	9,5%	17,0%
6. Dwelling with no heating	2,3%	0,9%	1,1%	1,2%	1,5%	3,2%	0,9%	2,5%	3,0%	2,6%	0,0%	0,0%	0,3%	1,4%	0,8%
5. Other type of energy	0,0%	0,1%	0,0%	0,3%	0,1%	0,0%	0,1%	0,0%	0,3%	0,0%	0,0%	0,0%	0,2%	0,0%	0,1%
4. Solar energy	0,0%	0,0%	0,0%	0,0%	0,1%	0,0%	0,1%	0,0%	0,1%	0,3%	0,0%	0,0%	0,0%	0,0%	0,3%
3. Electricity	6,0%	5,9%	9,2%	8,7%	10,2%	31,0%	26,2%	34,3%	39,6%	41,7%	20,3%	51,3%	64,5%	79,1%	74,5%
2. Liquid and gaseous fuels	0,5%	0,4%	0,6%	0,8%	0,7%	0,7%	0,4%	0,4%	0,4%	0,5%	0,0%	0,0%	7,2%	0,2%	1,1%
1. Solid fuels	57,9%	73,8%	71,0%	67,6%	61,6%	37,5%	70,2%	53,0%	35,6%	19,7%	23,7%	48,3%	27,8%	9,9%	6,1%

Figure 23 Share of buildings with central heating (Monstat 2011)



	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
No data (central heating)	31%	17%	17%	20%	24%	24%	2%	10%	20%	33%	51%	1%	3%	9%	16%
Without central heating	67%	78%	75%	70%	66%	75%	93%	84%	74%	62%	49%	98%	95%	88%	77%
With central heating	2%	5%	8%	9%	9%	1%	4%	6%	5%	5%	0%	1%	2%	3%	7%

Figure 24 Share of buildings with installed water pipes (Monstat 2011)



Air-conditioning systems

In Montenegro, 54 percent of dwellings are equipped with mechanical cooling systems, and the share is increasing significantly. In 2005 it was just 21.4 percent (Monstat 2014). These are predominantly decentralised systems (split units). Most of the cooling units are reversible, thus they are used also for heating, although this cannot be supported by statistical data.

Unfortunately, there are no data about the distribution of cooling systems per climate zone, although it is probable that the distribution is not balanced. In climate zone 3, air-conditioning systems are not typical, while they are frequent in climate zones 1 and 2.

According to national regulations, cooling devices with the lowest efficiency have an energy efficiency value (EER) of <2.0.

III. Calculation method and main assumptions

Energy calculations

As already explained in Section II, the building type matrix was based on the existing Serbian building typology. Although there are fewer building types in Montenegro, each Montenegrin building type has a corresponding Serbian type. The energy calculation models and results are described in Jovanović Popović et al. (2013). However, although the Serbian building types cover the Montenegrin typology with respect to building geometry and structure, there are two important differences: first the climate, and second the energy sources and the corresponding supply systems. The calculations therefore had to be adjusted to conditions in Montenegro and the energy performance results for the Serbian building types had to be modified. For this reason, correction factors were applied.

Definition of the present state and retrofitting options

In the model, three renovation scenarios were developed for all building types, two of them representing a complex renovation package. The complex packages consist of measures for upgrading the building envelope, and the heating, cooling and DHW systems. For the building envelope, the same measures were applied as for the Serbian building types, while for the service systems different solutions were necessary. The measures for upgrading the building envelope are explained in detail in Jovanović Popović et al. (2013). The building types with corresponding Serbian typology are shown in Table 5.

The existing state of the building stock was modelled taking into account the following factors:

- In Montenegro there are three climate zones characterised by different degree days (Figures 25 and 26). The heating energy demand was calculated for all building types for all three climate zones. It was also applied for retrofitting options.
- In Montenegro, both conventional wood-burning stoves and low-efficiency electric air-to-air heat pumps are widely used. Taking into account only the more frequently used system would have led to a significant error in the national projection. Therefore, in the energy calculations, the two heating modes were modelled as a fictive bivalent system and the ratios of the two systems were equivalent to the national shares.

The “business as usual” (BAU) scenario includes what is nowadays the most frequently applied renovation option — that is, the changing of windows. In this case, a simplified estimate of 20 percent energy saving was taken into account for all building types.

The “standard” scenario includes interventions related to each building component in order to achieve compliance with the minimum requirements foreseen in the case of major renovation. In the case of buildings constructed before 2000, major renovations are rather likely. The standard scenario in this case therefore includes a set of interventions for upgrading the building envelope from the point of view of insulation. In addition, high-efficiency wood pellet stoves are introduced in smaller buildings, while in larger buildings single-room air-to-air split system heat pumps with cooling, with a better coefficient of performance (COP), are introduced. Central solar hot water systems are introduced to cover at least 40 to 70 percent of DHW demand.

The “ambitious” scenario goes beyond the building regulations related to the building envelope. Building service systems are still based on two main energy

Table 5 Equivalent building types in the Montenegrin and Serbian typology (geometry and structures only)

	Montenegro	Serbia	Montenegro	Serbia	Montenegro	Serbia
Before 1945	A1	A1	B1	A3	C1	C3
1946–1970	A2	B1	B2	B3	C2	
1971–1990	A3	D1	B3	D3	C3	D4
1991–2000	A4	E1	B4	E3	C4	E4
2001–2011	A5	F1	B5	F3	C5	F4

sources (wood and electricity), but better system efficiencies are considered. In all cases central solar collectors are introduced.

Climate

As already mentioned, Montenegro is divided into three climate zones (Figure 25). The results of the Serbian calculations for heating energy consumption were corrected by the degree days of the corresponding climate zone (Figure 26).

Heating systems

In Montenegro, non-central systems (room heating) dominate, while in Serbia apartment heating and central heating are also frequent. Thus the heating, cooling and hot water systems were completely revised.

The modified systems correspond to different system efficiencies and calculation results.

Regarding the devices used for heating, there are no statistical data per dwelling or building type. National regulations prescribe/suggest the efficiency values for heating devices, depending on fuel or type, as shown in Table 6.

Considering that there are no further data regarding the characteristics of heating devices per building type (no survey has been performed with respect to these data in Montenegro), in the building type models the most frequent systems were incorporated. For the renovation options, the tradition of non-central (mostly per room) systems based on wood and electricity were taken into account, as shown in Tables 7, 8 and 9).

In many building types, wood stoves and air heat pumps are both very frequent, thus, as explained above, fictive bivalent systems were developed in the building type matrix.

Figure 25 **Climate zones in Montenegro (Zone 1: orange, Zone 2: yellow, Zone 3: blue)**

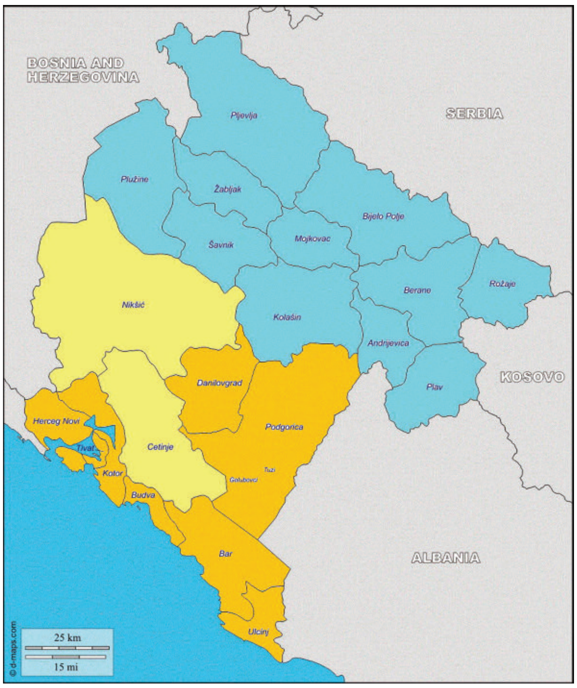


Figure 26 **Heating degree day (HDD) values per climate zone** (Ministry of Economy 2013a)

Montenegro HDD = 2386[1]		
I ZONE	**II ZONE**	**III ZONE**
HDD = 1623	HDD = 2528	HDD = 3388
Bar	Nikšić	Andrijevica
Budva	Cetinje	Berane
Danilovgrad		Bijelo Polje
Herceg Novi		Žabljak
Kotor		Kolašin
Podgorica		Mojkovac
Tivat		Plav
Ulcinj		Plužine
		Pljevlja
		Rožaje
		Šavnik

Table 6 Typical efficiency factors of heat production units in Montenegro

Fuel	Stove/boiler	%
Liquid fuel	Cast (before 1970)	60
	Mechanical nozzle	70–78
	Standard (medium efficiency)	83–89
Electrical energy	Central	100
Natural gas, LPG	Conventional	55–65
	Standard (medium efficiency)	78–84
	Condensing	90–97
Solid fuel	Conventional	45–55
	Modern	55–65
	State of the art	75–90

Table 7 Definition of present state and retrofitting options for heating systems in Montenegro

	Present state and BAU renovation	Standard renovation	Ambitious renovation
A1	Wood stove – η = 0.6	Wood pellet stove – η = 0.85	Centralised heating system with wood pellet boiler and automatic regulation of temperature and hot water preparation
A2			
A3			
A4	Heat pump – SCOP = 2.2		
A5			
B1	Wood stove – η = 0.6	Wood pellet stove – η = 0.85	Centralised heating system with wood pellet boiler and automatic regulation of temperature and hot water preparation
B2			
B3			
B4	Heat pump – SCOP = 2.2		
B5			
C1	Wood stove – η = 0.6	Heat pump – SCOP = 3	Heat pump – SCOP = 4
C2			
C3			
C4	Heat pump – SCOP = 2.2		
C5			

Table 8 Energy sources for heating: Present state and BAU improvement

		Electricity share	Biomass share
		%	%
A1–5	Present state and BAU improvement	9	91
A2	Present state and BAU improvement	7	93
A3	Present state and BAU improvement	11	89
A4	Present state and BAU improvement	11	89
A5	Present state and BAU improvement	14	86
B1	Present state and BAU improvement	45	55
B2	Present state and BAU improvement	27	73
B3	Present state and BAU improvement	39	61
B4	Present state and BAU improvement	53	47
B5	Present state and BAU improvement	68	32
C1,C2	Present state and BAU improvement	46	54
C3	Present state and BAU improvement	70	30
C4	Present state and BAU improvement	89	11
C5	Present state and BAU improvement	92	8

Table 9 Energy sources for heating: Standard (improvement 1) and ambitious (improvement 2) renovation

		Electricity share	Biomass share
		%	%
A1–5	Improvements 1 and 2	0	100
B1–5	Improvements 1 and 2	0	100
C1–5	Improvements 1 and 2	100	0

Cooling systems

In Montenegro, air-conditioning systems are predominantly non-central systems (split units). Most cooling units are reversible, thus they are also used for heating, although this cannot be supported by statistical data. According to the national regulations, cooling devices with the lowest efficiency have an energy efficiency value (EER) of <2.0. For the retrofitting options, non-reversible systems with an EER of 3 or an EER of 4 were considered.

In family houses and small multi-apartment buildings (types A and B), renovation options based on wood pellets were applied for heating, while for large buildings reversible split systems were considered. As a consequence, in large buildings cooling is available without extra measures. For building types with pellet heating, cooling can be installed only at extra cost.

In climate zone 3, cooling is not used (Table 10).

Table 10 Definition of present state and retrofitting options for cooling systems in Montenegro

	Present state and BAU renovation	Standard renovation	Ambitious renovation
A1–5	Heat pump – EER = 2	Heat pump – EER > 3	Heat pump – EER > 3
B1–5	Heat pump – EER = 2	Heat pump – EER > 3	Heat pump – EER > 3
C1–5	Heat pump – EER = 2	Same as for heating (no additional unit)	Same as for heating (no additional unit)

Domestic hot water systems

Montenegrin households typically produce sanitary hot water using an electric boiler (generally with a capacity of 80 litres and 2.5 kW electrical power).

In the complex renovation options, central sanitary hot water production (solar water-heating systems) is more easily applied (Table 11). A solar-based system is not able to meet the demand for DHW throughout the year, thus auxiliary heating is necessary. This may be in the form of direct electricity, heat pump or central wood pellet boiler, depending on the applied heating system.

The net heat demand for domestic hot water is calculated based on the daily hot water consumption per person, taking into account the average number of inhabitants. For family houses, 35 litres per day per person was used, and for multi-apartment buildings 30 litres per day per person. The temperature difference for hot water preparation was considered as 50 degrees. As a country average the result — taking into account the number of inhabitants per building type and the number and size of dwellings per building type — was 31.9 kWh/m^2 per year. This weighted average figure was applied for all further calculations.

Partial heating and cooling

Typically in Montenegro only a part (one or two rooms) of a dwelling is heated in order to save energy and costs. This is technically easy as most systems heat per room. In addition, the heating system is typically not turned on all day long. Heating overnight is rare. The maximum time that heating is on in households is therefore 24-6=18 hours, and the typical daily heated hours are between 10 and 14, although no statistics are available on this issue. Although the mild winter in climate zones 1 and 2 makes it relatively easy to use intermittent and partial heating and put up with lower comfort levels, in the future it is predicted that comfort requirements will increase, making under-heating less frequent, thus the significance of under-heating and partial heating will decrease. In the retrofitting options we therefore assumed an increase in heated floor area and daily heated hours. It should also be mentioned that in well-insulated buildings the impact of internal heat flows is greater and the indoor air temperature more balanced.

As discussed above, in Montenegro approximately 54 percent of dwellings are fitted with mechanical cooling systems (Monstat 2011). However, in these dwellings it can be assumed that many people do not use their domestic air-conditioning system in order to save electricity costs, or that they use it in only one or two rooms. In climate zones 2 and 3, cooling is not typical.

Real energy consumption for heating and cooling is thus significantly lower than the theoretical figures given by the model, assuming full heating. The concrete correction factors for partial heating and cooling and daily heated hours applied in the modelled options are detailed in calculation Excel sheets (available at www.sled.rec.org). However, it should be highlighted that the estimated figures should be handled with caution, as no statistics are available on partial heating and cooling. Statistical surveys are recommended, in order to obtain a more precise picture.

System efficiencies

The delivered energy is calculated from the net heating energy demand (Q_{ND}) per energy source:

$$Q_{delivered} = \frac{Q_{ND}}{\eta_t}$$

The system efficiency (η_t):

$\eta_t = \eta_b \cdot \eta_p \cdot \eta_c$ where:

η_b = boiler (source) efficiency

η_p = piping (distribution) efficiency

η_c = control (regulation) efficiency

The concrete efficiency figures applied in the modelled options can be found in the Excel sheets available at www.sled.rec.org.

Primary energy and CO_2 emission factors

Primary energy consumption ($Q_{primary}$) is calculated as the sum of the delivered energy ($Q_{delivered}$) multiplied by the primary energy factors ($f_{p,source}$) of the energywares:

$$Q_{primary} = \sum Q_{delivered} \cdot f_{p,source\ i} \quad \left[{}^{kWh}/_{year}\right]$$

The annual CO_2 emissions from space heating and domestic hot water production are determined as follows:

$$m_{CO2} = \sum Q_{delivered} \cdot f_{CO2,source\ i} \quad \left[{}^{kg}/_{year}\right]$$

where

$f_{CO_2,source\ i}$ = the CO_2 emission factor of the energyware used by heat generator i.

The conversion factors for the determination of annual primary energy consumption and specific CO_2 emissions per energy carrier are shown in Table 12.

Table 11 **Definition of present state and retrofitting options for domestic hot water systems in Montenegro**

	Existing state and BAU renovation	Standard renovation	Ambitious renovation
A1	Electrical boiler	SWH system	SWH system for hot water preparation connected to centralised heating system
A2			
A3			
A4			
A5			
B1	Electrical boiler	SWH system	SWH system for hot water preparation connected to centralised heating system
B2			
B3			
B4			
B5			
C1	Electrical boiler	Centralised SWH system for hot water preparation	Centralised SWH system for hot water preparation
C2			
C3			
C4			
C5			

Table 12 **Conversion factors for determining annual primary energy consumption and specific CO_2 emissions per energy carrier** (Ministry of Economy 2013a; Szabó et al. 2015)

Energy carrier	Primary to final energy factor	Specific CO_2 emissions
	(kWh/kWh)	(kg/kWh)
Wood biomass	1.0	0.10
Electrical energy	2.5	0.59
Other fossil fuels	1.0	-
Solar energy	0.0	0.00

IV. Calculation results

The detailed energy calculation results per building type are provided in a separate Excel file, Montenegro_types_energy.xls, available at www.sled.rec.org. This file contains the most relevant input data and the results for the heating, cooling and hot water energy demand of each building type. As mentioned, the building models (net heating energy demand calculations) are based on the energy calculations in Jovanović Popović et al. (2013) and the considerations outlined in earlier chapters.

Net energy demand and primary energy consumption in the existing building stock

A summary of the results is presented in Figures 27 and 28. In the diagrams, detached houses and small multi-apartment buildings were assumed to have a wood stove for heating, or poor-efficiency reversible split systems for heating and cooling. This can be regarded as typical. In the diagram, the heating of the entire building was considered.

The progress in net heating demand shows that the thermal characteristics of the building stock have somewhat improved over time, although significant improvement can be seen only in the last decade. It should be noted that although the thermal properties of detached houses are worse than those of larger buildings, due to the unfavourable surface to volume ratio, the primary energy results show the opposite. This can be explained by the heating sources considered: the primary energy factor of wood was assumed to be 0.1, while for electricity, which was assumed to be the energy source in larger buildings, the respective factor is 2.5.

The share of DHW primary energy consumption is relatively large, due to the fact that electric water heaters were taken into account, which have a high primary energy factor. Demand is also high compared to other countries (31.9 kWh/m^2/year). In all building types heating dominates in the total energy demand.

The values for cooling should be considered with caution. The building typology was designed to model heating, as heating is the most important area of energy use in Montenegrin households. The typology is not appropriate to model cooling, because the most important factors determining cooling demand — that is, the ratio of glazed surfaces, orientation and shading devices and neighbouring environment — were not considered (due to a lack of statistical data). However, as cooling has far less significance in the national energy balance than heating, and as there are no appropriate statistical data for creating a building typology for modelling the building stock for cooling, we decided to apply the same typology for cooling and heating. The net cooling demand figures are educated guesses made by experts based on the calculation results of other countries (Albania and Hungary). For the more appropriate modelling of cooling demand another typology should be designed, although before this can happen, statistical data must be collected about the building characteristics that determine cooling.

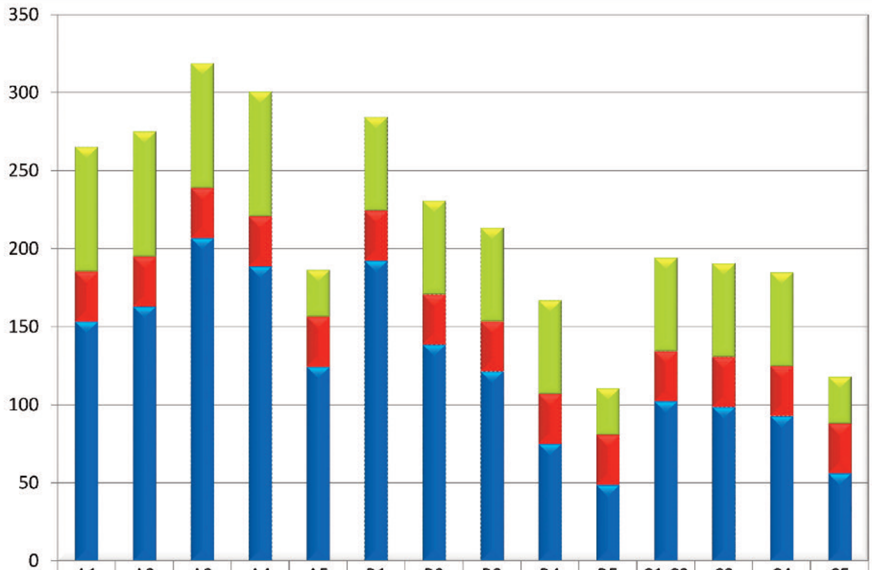
It should be noted that the figures correspond to full heating, while in an average household partial and intermittent heating and cooling are typically applied. Results for all climate zones and partial heating/cooling can be found in the file Montenegro_types_energy.xls, available at www.sled.rec.org.

Net energy demand and primary energy consumption in the retrofitting options

The two complex retrofitting options lead to very significant energy savings in terms of both net energy demand (52 percent and 64 percent mean savings) and primary energy consumption (72 percent and 83 percent mean savings). Primary energy savings are particularly high because of the increasing share of wood rather than electricity (wood has a lower primary energy factor).

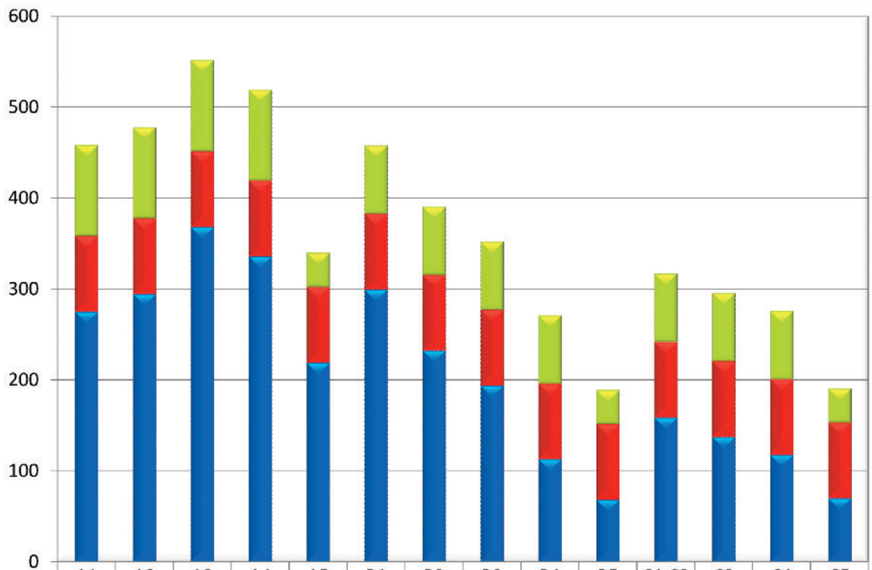
It should be noted once again that the figures for the original state and the BAU option correspond to full heating, leading to an overestimation. In an average household, partial and intermittent heating and cooling are typically applied. Results for all climate zones and partial heating/cooling can be found in the file Montenegro_types_energy.xls, available at www.sled.rec.org.

Figure 27 Net energy demand of building types (present state, full heating, climate zone 1)



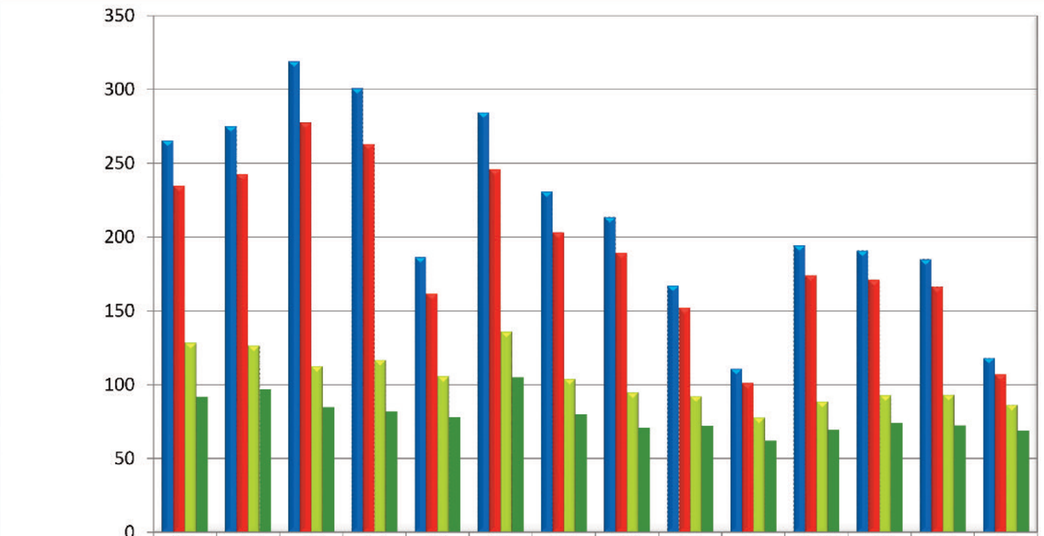
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1,C2	C3	C4	C5
Cooling [kWh/m2a]	80	80	80	80	30	60	60	60	60	30	60	60	60	30
DHW [kWh/m2a]	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Heating (Z1) [kWh/m2a]	153	163	207	189	124	192	139	122	75	49	102	99	93	56

Figure 28 Primary energy consumption of building types (present state, full heating, climate zone 1)



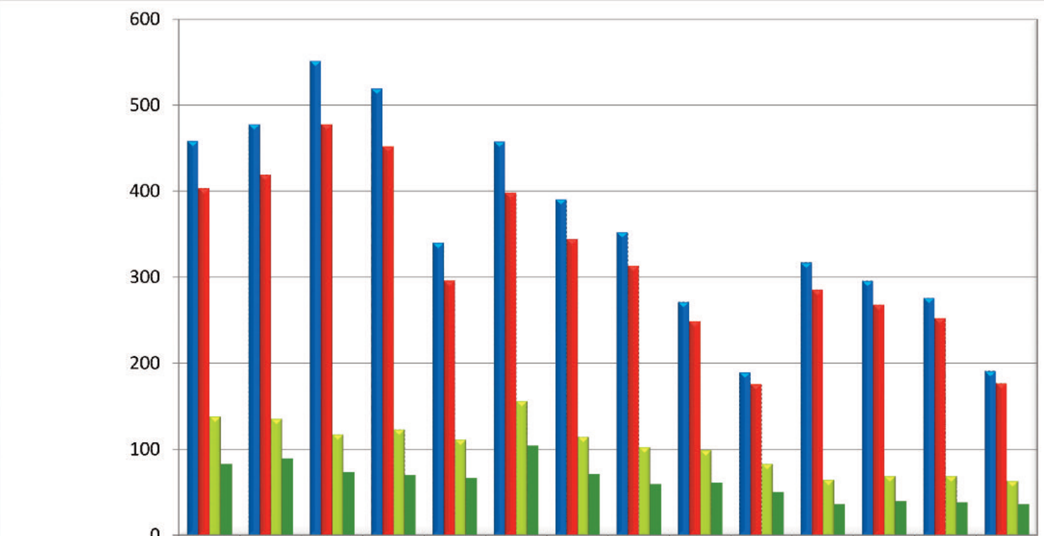
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1,C2	C3	C4	C5
Cooling [kWh/m2a]	100	100	100	100	38	75	75	75	75	38	75	75	75	38
DHW [kWh/m2a]	83	83	83	83	83	83	83	83	83	83	83	83	83	83
Heating (Z1) [kWh/m2a]	275	295	368	336	219	300	232	194	113	69	159	138	118	70

Figure 29 Net energy demand of building types (present state and retrofitted states, full heating, climate zone 1)



	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1,C2	C3	C4	C5
present state	265	275	319	301	186	284	231	213	167	111	194	191	185	118
improvement 1	235	242	278	263	162	246	203	189	152	101	174	171	166	107
improvement 1	128	126	113	117	106	136	104	95	92	78	88	93	93	86
improvement 2	92	97	85	82	78	105	80	71	72	62	70	74	72	69

Figure 30 Primary energy consumption of building types (present state and retrofitted states, full heating, climate zone 1)



	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1,C2	C3	C4	C5
present state	458	478	551	519	340	458	391	352	271	189	317	296	276	191
improvement BAU	403	419	478	452	296	398	344	313	249	176	285	268	252	177
improvement 1	138	135	117	123	111	156	114	102	99	83	65	69	69	63
improvement 2	83	90	74	70	67	104	72	60	61	50	36	39	38	36

Delivered energy consumption per energy source

For a sectoral analysis it is important to know the delivered energy consumption per energy source. For the current and BAU state we used estimates per building type based on national statistics for the proportion of energy sources (see Tables 2, 3 and 4 on pages 34 to 36). Only the two main energy sources, wood and electricity, were taken into account. The other sources were omitted.

In the retrofitted cases, the most probable options were taken into account depending on the building type. All results can be found in the file Montenegro_types_energy.xls, available at www.sled.rec.org.

CO_2 emissions

In relative terms, the reduction in CO_2 emissions is even greater than the primary energy savings. This is because in Montenegro the primary energy factor of wood is high compared to most countries (at 1.00), but the CO_2 emission factor is low. As wood has an increasing share in the renovation options the impact of these factors is significant.

All results can be found in the file Montenegro_types_energy.xls, available at www.sled.rec.org.

V. Investment costs and energy prices

Costs per measure and floor area: Building envelope

Investment costs are given by building type and measure (see Tables 13 and 14). The prices are average prices, which means that there is no differentiation between smaller and larger buildings. Prices include all system elements, although, depending on the present state of the building, there may be some additional work to remove old installations. The prices include labour costs and 19 percent VAT.

For sectoral modelling it was more appropriate to give the investment costs per heated floor area, rather than per unit area, therefore we calculated the costs per building type. The results are summarised in Tables 15 and 16.

Costs per floor area: Building service systems

Prices for building service systems were identified per building type and measure. These prices were later differentiated, taking into account the fact that for larger buildings, price discounts are applied (see Tables 17, 18 and 19). Prices include all system elements, although, depending on the present state of the building, there may be some additional work to remove the old installations. The prices include labour costs and 19 percent VAT.

In some cases, heating is supplied by reversible heat pumps that can also be used for cooling without additional cost. In other cases, cooling can be provided only by additional split systems (smaller, cheaper heat pumps).

Table 13 Investment costs per measure unit area: Standard improvement

	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2
	External wall	Ground floor	Floor construction in unheated attic	Floor construction in unheated area (basement)	Pitched roof (renovation)	Flat roof (renovation)	Windows
A1–5	30.00	-	20.00	25.00	-	-	150.00
B1–5	35.00	-	20.00	25.00	30.00	50.00	150.00
C1–5	40.00	-	20.00	25.00	30.00	50.00	150.00

Table 14 Investment costs per measure unit area: Ambitious improvement

	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2	EUR/m^2
	External wall	Ground floor	Floor construction in unheated attic	Floor construction in unheated area (basement)	Pitched roof (renovation)	Flat roof (renovation)	Windows
A1–5	40.00	50.00	30.00	35.00	-	-	150.00
B1–5	45.00	-	30.00	35.00	40.00	60.00	150.00
C1–5	50.00	-	30.00	35.00	40.00	60.00	150.00

Table 15 Investment costs per heated floor area: Standard improvement

	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1–2	C3	C4	C5
	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR /m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²
Walls (and arcade ceilings)	48.20	39.30	44.80	33.80	34.90	68.50	42.60	26.60	19.10	23.30	24.10	25.50	23.20	23.30
Windows	33.80	34.70	36.80	32.50	23.40	49.00	46.20	31.90	38.80	24.50	30.50	37.10	34.20	26.70
Floor construction in attic	25.00	25.80	12.90	11.50	12.80	9.50	4.90	4.80	3.80	3.90	3.20	2.00	2.60	3.20
Floor construction in unheated area (basement)	0.00	0.00	16.10	2.30	3.60	11.90	6.10	5.90	4.00	5.00	4.00	3.00	3.20	5.60
Flat roof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	3.00	0.00	0.20
Pitched roof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	1.30	1.90
Floor construction on ground	0.00	0.00	0.00	0.00	22.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total (envelope)	**107.00**	**99.70**	**110.60**	**80.20**	**93.30**	**138.90**	**99.70**	**69.20**	**65.70**	**57.70**	**61.90**	**67.60**	**64.50**	**60.90**
Heating system	25.00	25.00	25.00	25.00	25.00	22.50	22.50	22.50	22.50	22.50	35.00	35.00	35.00	35.00
Hot water system	25.00	25.00	25.00	25.00	25.00	22.50	22.50	22.50	22.50	22.50	40.00	40.00	40.00	40.00
Total (system)	**50.00**	**50.00**	**50.00**	**50.00**	**50.00**	**45.00**	**45.00**	**45.00**	**45.00**	**45.00**	**75.00**	**75.00**	**75.00**	**75.00**
Total (envelope + system)	**157.00**	**149.70**	**160.60**	**130.20**	**143.30**	**183.90**	**144.70**	**114.20**	**110.70**	**102.70**	**136.90**	**142.60**	**139.50**	**135.900**

Table 16 Investment costs per heated floor area: Ambitious improvement

	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1–2	C3	C4	C5
	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²	EUR/ m²
Walls	64.20	52.30	59.70	47.20	46.70	91.60	56.90	35.60	25.50	31.20	32.20	34.30	31.20	31.20
Windows	33.80	34.70	36.80	32.50	23.40	49.00	46.20	31.90	38.80	24.50	30.50	37.10	34.20	26.70
Floor construction in attic	37.50	38.60	19.30	17.30	19.20	14.30	7.30	7.10	5.70	5.90	4.90	3.10	3.90	4.80
Floor construction in unheated area basement)	0.00	0.00	22.60	3.20	5.10	16.60	8.50	8.30	5.60	7.00	5.60	5.20	4.40	7.80
Flat roof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	3.60	0.00	0.30
Pitched roof	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	1.80	2.50
Floor construction on ground	62.50	51.50	0.00	20.40	24.60	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Total (envelope)	**198.10**	**177.20**	**138.30**	**120.50**	**113.90**	**171.50**	**118.90**	**82.90**	**76.60**	**69.80**	**73.20**	**79.60**	**75.50**	**73.40**
Heating system	55.00	55.00	55.00	55.00	55.00	44.00	44.00	44.00	44.00	44.00	80.00	80.00	80.00	80.00
Hot water system	35.00	35.00	35.00	35.00	35.00	31.50	31.50	31.50	31.50	31.50	40.00	40.00	40.00	40.00
Total (system)	**90.00**	**90.00**	**90.00**	**90.00**	**90.00**	**75.50**	**75.50**	**75.50**	**75.50**	**75.50**	**120.00**	**120.00**	**120.00**	**120.00**
Total (envelope + system)	**288.10**	**267.20**	**228.30**	**210.50**	**203.90**	**247.00**	**194.40**	**158.40**	**152.10**	**145.30**	**193.20**	**199.60**	**195.50**	**193.40**

Table 17 Investment costs per heated floor area: Heating

	Standard renovation	Ambitious renovation
A1–5	Wood pellet stove – η = 0.85 (EUR 25/m^2)	Centralised heating system with wood pellet boiler and automatic regulation of temperature and hot water production (EUR 55/m^2)
B1–5	Wood pellet stove – η = 0.85 (EUR 22.5/m^2)	Centralised heating system with wood pellet boiler and automatic regulation of temperature and hot water production (EUR 44/m^2)
C1–5	Heat pump – SCOP >3 (price EUR 35/m^2)	Heat pump – SCOP >4 (price EUR 80/m^2)

Table 18 Investment costs per heated floor area: Cooling

	Standard renovation	Ambitious renovation
A1–5	Heat pump – standard (price EUR 10/m^2)	Heat pump – standard (price EUR 10/m^2)
B1–5	Heat pump – standard (price EUR 10/m^2)	Heat pump – standard (price EUR 10/m^2)
C1–5	Same as for heating (no additional cost)	Same as for heating (no additional cost)

Table 19 Investment costs per heated floor area: Domestic hot water

	Standard renovation	Ambitious renovation
A1–5	SWH system (price EUR 25/m^2)	SWH system for hot water production connected to centralised heating system (price EUR 35/m^2)
B1–5	SWH system (price EUR 22.5/m^2)	SWH system for hot water production connected to centralised heating system (price EUR 31.5/m^2)
C1–5	Centralised SWH system for hot water production (price EUR 40/m^2)	Centralised SWH system for hot water production (price EUR 40/m^2)

Energy prices

In Montenegro, the most important energy carrier is electricity (almost three-quarters of all energy expenditure per household). Nevertheless, fuelwood is also a significant energy carrier, especially for rural households and urban households in central and northern Montenegro. Other energy carriers represent a small share in the energy balance.

Electricity

The price of electricity is defined by the Montenegrin Regulatory Agency for Energy according to a predefined methodology based on the approved revenue of the Montenegrin Power Company (EPCG), which is the only supplier of electricity for the residential sector. The price is typically defined in advance for three years (the regulatory period), but can be corrected for each year of that period. The price depends on several consumer characteristics:

- Voltage level of grid connection (110 kV, 35 kV, 10 kV or 0.4 kV). Residential consumers (households) are all connected to a 0.4 kV supply (i.e. low voltage).
- Number of phases (three- or one-phase connection). Three-phase connection is the dominant type of connection for residential consumers, although in rural areas there may be single-phase connections.
- Power demand metering. All high-voltage connections, and those low-voltage connections that correspond to commercial consumers, are metered. Residential consumers do not have power demand metering, thus the power demand of residential consumers is not billed.

- Reactive energy metering. This feature is not available for residential consumers (i.e. it is not billed).

Another important feature is that there are two tariff levels in Montenegro:

- High tariff
  - From 07.00 to 23.00 on every day except Sunday
- Low tariff
  - All day Sunday and from 23.00 to 07.00 on all other days of the week.

Thus most residential consumers are connected to the 0.4 kV grid, do not have power demand or reactive power metering, and predominantly have a three-phase connection with two tariff levels. The remaining residential consumers have a single-phase connection and a single tariff level. The electricity prices for these two types of residential consumers are defined according to Tables 20 and 21.

As the tables show, the electricity price is defined by more than simply the amount of electricity consumed. There are some fixed costs (power supply fee, market operator fee and a part of the fee for distribution capacity usage), and in the case of two-tariff metering the manner in which electricity is used has a strong impact on the total price. In order to define the total average price of electricity per kWh, it is therefore necessary to identify the average electricity consumption per month, as well as the ratio between electricity consumption during high-tariff hours compared to low-tariff hours.

Table 20 Electricity price for households with two-tariff meters (Regulatory Agency for Energy, 2014)

	Standard renovation option	Cost	Unit
Active power consumption	High tariff	4.6596	cEUR/kWh
	Low tariff	2.3298	cEUR/kWh
Transmission capacity usage		0.3543	cEUR/kWh
Participation in transmission losses	High tariff	0.1954	cEUR/kWh
	Low tariff	0.0977	cEUR/kWh
Distribution capacity usage		3.0226	cEUR/kWh
		1.3228	EUR
Participation in distribution losses	High tariff	0.5318	cEUR/kWh
	Low tariff	0.2659	cEUR/kWh
Power supply fee		1.6556	EUR
Market operator fee		0.058	EUR

Table 21 Electricity price for households with single-tariff meters (Regulatory Agency for Energy 2014)

	Cost	Unit
Active power consumption	3.6974	cEUR/kWh
Transmission capacity usage	0.3543	cEUR/kWh
Participation in transmission losses	0.1551	cEUR/kWh
Distribution capacity usage	3.0226	cEUR/kWh
	1.3228	EUR
Participation in distribution losses	0.422	cEUR/kWh
Power supply fee	1.6556	EUR
Market operator fee	0.058	EUR

If it is assumed that average electricity consumption per month is 600 kWh, and that the ratio between high-tariff and low-tariff electricity consumption is 2:1 (typically the case in households that do not consider the tariff period when consuming electricity), the price of consumed electricity per kWh is presented in Table 22.

It should be stressed that the electricity price presented in Table 22 for two-tariff metering is lower for the same ratio of high-tariff to low-tariff electricity consumption if the total electricity consumption is doubled to 1,200 kWh. The corresponding electricity price is presented in Table 23. This is due to the lower share of fixed costs in the total cost of electricity consumption.

A similar conclusion can be drawn in the case of the same electricity consumption (600 kWh), but with a different ratio between high-tariff and low-tariff consumption. If this ratio is 1:1, the corresponding electricity price is given in Table 24.

The amount of consumed electricity also has an impact on the electricity price per kWh for single-tariff residential consumers, and the corresponding price for the monthly consumption of 1,200 kWh is given in Table 25.

Taking into account the above analysis, an average price of cEUR 10/kWh for all residential consumers can be adopted. (This price is often used by the Montenegrin Power Company and Regulatory Agency for Energy for rapid calculations.)

Fuelwood

Traditionally, fuelwood is the main energy carrier for heating purposes used by rural households, and also by numerous urban households. According to surveys (FODEMO 2015), fuelwood is the primary heating energy carrier in rural and urban households in northern Montenegro (Pljevlja, Žabljak, Šavnik, Plužine, Berane, Andrijevica, Plav, Rožaje, Kolašin i Mojkovac). Fuelwood is used in significant amounts in Podgorica, Danilovgrad and Nikšić. The fuelwood market is characterised by two basic products: so-called metre fuelwood and chopped fuelwood (Figure 31).

Table 22 Electricity price per kWh for a household with 600 kWh consumption (HT:LT = 2:1)

Metering type	Cost (cEUR/kWh)	VAT (19%) (cEUR/kWh)	Total cost (cEUR/kWh)
Two-tariff metering	9.11	1.73	10.84
Single-tariff metering	8.16	1.55	9.71

Table 23 Electricity price per kWh for a household with 1,200 kWh consumption (HT:LT = 2:1)

Metering type	Cost (cEUR/kWh)	VAT (19%) (cEUR/kWh)	Total cost (cEUR/kWh)
Two-tariff metering	8.85	1.68	10.54

Table 24 Electricity price per kWh for a household with 600 kWh consumption (HT:LT = 1:1)

Metering type	Cost (cEUR/kWh)	VAT (19%) (cEUR/kWh)	Total cost (cEUR/kWh)
Two-tariff metering	8.62	1.64	10.26

Table 25 Electricity price per kWh for a household with 1,200 kWh consumption

Metering type	Cost (cEUR/kWh)	VAT (19%) (cEUR/kWh)	Total cost (cEUR/kWh)
Single-tariff metering	7.9	1.5	9.4

As shown in Figure 32, fuelwood is mainly supplied from:

- a person's own forest or a friend's forest;
- traders;
- a firewood yard; or
- a state forest.

Traders are the predominant suppliers to rural and urban households, although rural households significantly rely on their own forests for fuelwood supply.

The price of fuelwood depends on the availability of resources, the need for transportation, and the level of fuelwood preparation (metre fuelwood or chopped fuelwood). Fuelwood is billed per spatial metre (prm), although in the FODEMO project (FODEMO 2015) the price of fuelwood is recalculated per cubic metre, which is the standard technical measure. As shown in Table 26, the price of fuelwood per cubic metre therefore differs in Montenegrin municipalities. Consumption per city is shown in Figure 33.

Figure 31 Fuelwood products on the market

Figure 32 Fuelwood supply (Monstat)

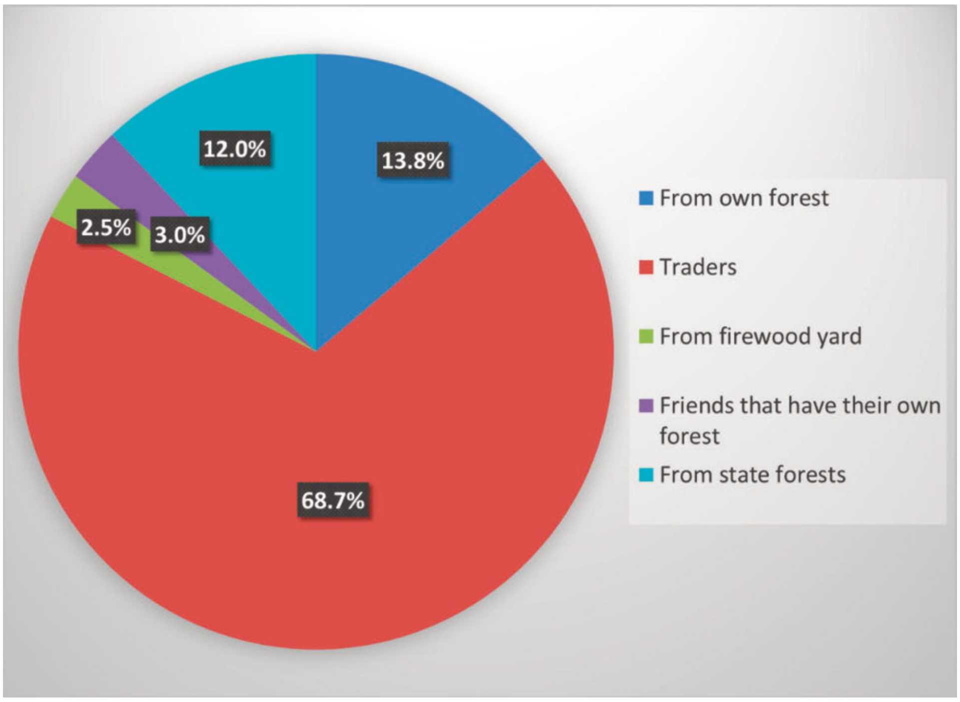


Figure 33 Consumption of fuelwood per city in cubic metres (FODEMO 2015)

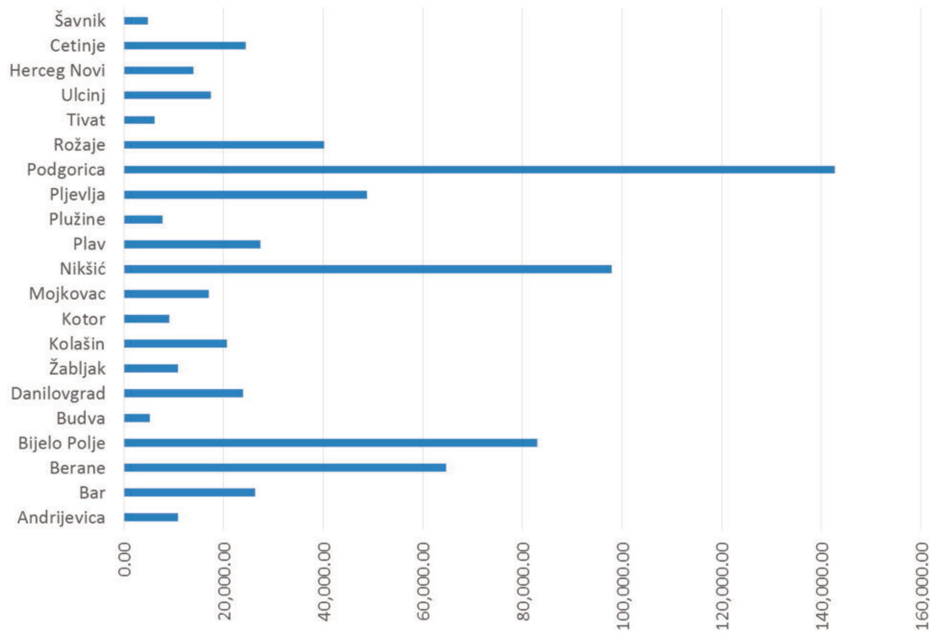


Table 26 Average total fuelwood price per cubic metre

	Cost (EUR)	VAT 19% (EUR)	Total cost (EUR)
Andrijevica	36.62	6.96	43.58
Bar	61.15	11.62	72.77
Berane	35.40	6.73	42.13
Bijelo Polje	41.99	7.98	49.97
Budva	55.15	10.48	65.63
Danilovgrad	61.98	11.78	73.76
Žabljak	31.44	5.97	37.41
Kolašin	35.27	6.70	41.97
Kotor	74.64	14.18	88.82
Mojkovac	33.18	6.30	39.48
Nikšić	51.32	9.75	61.08
Plav	36.74	6.98	43.72
Plužine	27.45	5.22	32.67
Pljevlja	19.71	3.75	23.46
Podgorica	54.03	10.27	64.30
Rožaje	39.00	7.41	46.41
Tivat	55.04	10.46	65.50
Ulcinj	43.07	8.18	51.25
Herceg Novi	61.54	11.69	73.24
Cetinje	49.54	9.41	58.95
Šavnik	27.71	5.27	32.98
Montenegro	45.00	8.55	53.55

PART 2

Modelling the transformation to a low-carbon residential building stock

VI. Methodology

Modelling approach

In order to assist in the development of energy efficiency and climate mitigation policies for the residential building sector in Montenegro, we designed and applied a bottom-up simulation model. The model aggregated information on energy consumption by end use at the level of representative buildings to a sector balance at country level. The model also calculated the costs of consumed energy. Assuming the retrofitting costs of representative buildings, we calculated the retrofitting costs at country level. The model also made it possible to run scenarios with different levels of policy effort, assuming the transformation of the building stock to a low-energy and low-carbon level by a particular target year or at a particular rate.

Building age

We classified the entire residential building stock into six age categories, three type categories, and three climate zones. This classification followed the building typology prepared in Part 1 of the present book. The first difference from that typology is that the age category 2001–2011 was extended to 2015. The second difference is that we added a category of buildings constructed after 2016. Their geometrical characteristics correspond to those of buildings constructed in 2001–2011. We assumed that new buildings are constructed according to the same distribution by climate zone as existing buildings.

The age categories are buildings constructed:

- before 1945;
- between 1946 and 1970;
- between 1971 and 1990;
- between 1991 and 2000;
- between 2001 and 2015; and
- after 2016.

The building types are:

- small buildings;
- medium-sized buildings; and
- large buildings.

The climate zones are:

- zone 1, coastline;
- zone 2, moderate; and
- zone 3, mountainous.

Altogether, we therefore considered 18 representative buildings located in three climate zones. For more details on the building typology for Montenegro, see Part 1 of the present book.

Modelling scope and boundaries

Our model assessed only thermal energy services delivered to residential buildings in Montenegro — namely space heating, space cooling and water heating. We did not cover energy use for electrical appliances, lighting or cooking. The latter three energy services represent a large share in the residential sector balance, thus it is important to bear in mind that our calculated levels of energy consumption and CO_2 emissions are far lower than the total sector levels.

The retrofitting options include both the improvement of the thermal envelope and the changing of technical systems, which often implies a fuel switch. Improving the thermal envelope means retrofitting walls, roofs, floors and windows. Better technical systems are more efficient systems for water heating, space heating and space cooling. Depending on the technical and economic feasibility, households may switch to solar, biomass or electricity as energy sources. We do not consider the impact of climate change on space heating and cooling patterns (see Part 1 for details).

The model includes the illegal building stock. It does not cover buildings used for temporary purposes (holiday homes) or abandoned buildings. The model includes the non-inhabited building stock (see Section VII, page 69, for details about their treatment).

The base year for our model is 2014, and it is calibrated to the energy balances estimated for 2013. The model is only applicable to the period up to 2030. We estimated the building stock turnover until 2070, but this only serves to gain an understanding of the number of existing buildings that remain by this point, and the number of new buildings.

In terms of environmental impacts, we calculated only CO_2 emissions. We considered both direct and indirect emissions in our analysis. Direct emissions are those originating from fuel combustion that takes place in buildings. Section III of the present book contains information about the emission factors of fuels used in residential buildings (page 46). Indirect emissions are those that are produced in the transformation sector and accounted on the supply side according to the IPCC guidelines (IPCC NGGIP online), but associated with energy commodities consumed in energy-using sectors. In our case, indirect emissions include emissions from electricity use.

Modelling steps

Figure 34 illustrates the stepwise procedure for our modelling. Our team of national and international architects prepared the country's building typology, calculated building energy performance by end use, and assessed the possible building retrofitting packages and the associated costs at the level of individual representative buildings. This information is documented in detail in Part 1.

In Part 2 we focus on how we aggregated this information to the sector level and designed scenarios for the sector's energy consumption and CO_2 emissions in the future with different levels of policy effort. First we developed a building stock model to estimate the building floor area and its structure by representative buildings and climate zone up to 2070. We then married the data from the building stock model with the energy consumption by representative building to calculate the energy balance at sector level. The results obtained were compared and calibrated to the sector energy balance available from national public statistics.

Next, based on assumptions concerning likely technological, market and policy developments, we calculated the sector's energy consumption and associated CO_2 emissions in the business-as-usual reference scenario. Together with policy makers, we then formulated policy packages aimed at ensuring that buildings become low energy and low carbon in the long-term future. Finally, we calculated energy savings, CO_2 emissions avoided, saved energy costs and investments required in relation to the realisation of the packages.

Figure 34 Modelling steps

Part 1	Part 2
Step 1: Development of the building typology	Step 5: Construction of the building stock model
Step 2: Calculation of building energy performance at present	Step 6: Construction and calibration of the sector energy balance in the base year
Step 3: Calculation of possible retrofitting packages (business-as-usual, standard and ambitious options)	Step 7: Calculation of baseline energy consumption and CO_2 emissions until 2030
Step 4: Calculation of the cost of the retrofitting packages	Step 8: Formulation of policy packages and evaluation of their impacts and associated costs

Involvement of sector stakeholders

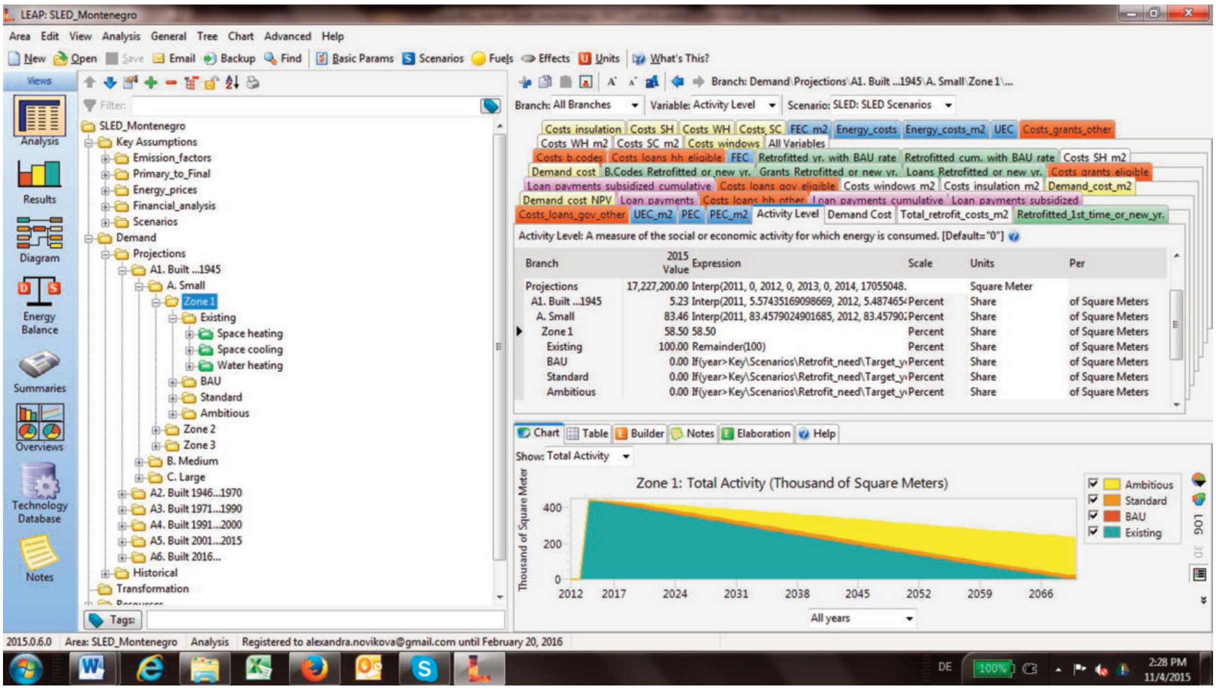
In order to make the project results useful for policy making in Montenegro, we communicated our progress to national policy makers and experts and incorporated their feedback into our work. We conducted interviews on adopted, forthcoming and other potentially useful policies and included this information into the business-as-usual and low-energy/low-carbon scenarios. The modelling results were presented in two rounds, when we received additional data, comments and requests.

The model itself, with the underlying input data, was provided to national policy makers and experts to use and modify according to their needs. It is also available on request for use by other experts, subject to proper referencing and acknowledgement.

Modelling tool

As a modelling tool, we used the Long-Range Energy Alternatives Planning System (LEAP) software developed by the Stockholm Environment Institute. The LEAP software is widely used in energy policy analysis and climate change mitigation assessment. Figure 35 illustrates the Montenegrin model in this software.

Figure 35 The Montenegrin model in the LEAP software



VII. Building stock model

Household trends

The evolution of the building stock is driven above all by the country's demographic situation. For this reason, we first calculated the number of households and the demand for dwellings over the modelling period.

In order to calculate the number of households, we relied on past population data from censuses carried out in Montenegro in 2003 and 2011 (Monstat 2003; Monstat 2011). We assumed a population growth up to 2030 according to the medium scenario of the Energy Strategy of Montenegro up to 2025 (Ministry of Economy 2007). For 2031–2070, we assumed the continuation of past population trends. Based on these assumptions, the population will grow to 640,000 in 2030; 661,000 in 2050; and 682,000 in 2070.

We assumed that, in line with overall European trends, the average number of persons per household in Montenegro would decrease. This change occurs due to factors such as population ageing, fewer children per family, and a higher share of monoparental households (European Commission 2011). According to the Montenegrin censuses (Monstat 2003; Monstat 2011), the average number of persons per household was 3.4 in 2003 and 3.2 in 2011. If the trend continues, this indicator will reach 2.8 persons per household in 2030; 2.4 in 2050; and 2.0 in 2070. This last value is the same as the average number of persons per household in Europe by 2050 (European Commission 2011). According to the latest census (Monstat 2011), there were 1.02 households per dwelling, and this number is assumed to be constant.

Based on the expected trends for population growth and persons per household, we estimated the total number of households. According to our calculations, the number of Montenegrin households will grow from 200,000 in 2015 to 232,000 in 2030, and will reach 281,000 in 2050 and 341,000 in 2070.

Figure 36 shows the indices for population, persons per household and number of households up to 2070. In 2070, the population of Montenegro will be 9 percent higher than the 2015 level; the number of persons per household will reach 64 percent of the 2015 level; and the number of households will be 70 percent higher than in 2015.

Remaining stock of existing buildings and dwellings

Data are not available on the number of buildings and dwellings per age category at two points in time in Montenegro, thus it is not possible to calculate the demolition rate of the residential building stock based on statistical evidence. We therefore had to use more assumptions when calculating the demolition rate than we did for other countries in South Eastern Europe. Once a new census, using the same data format as the 2011 census, is issued, it will be useful to make a more accurate estimation of the demolition rate than is possible in the current book.

The mortality trends of many technologies tend to follow a so-called Weibull curve, even though the useful lifetimes of these technologies differ (Weibull 1951; Welch and Rogers 2010). The curve presents the fraction of remaining units and is described by the following equation:

$$Fraction\ of\ units\ remaining\ (t) = e^{-(\frac{t-c}{a})^b}$$

where

t= year

a= scale factor

b= shape factor

c= location parameter

The mean lifetime of units could be estimates as:

$$Mean\ lifetime = a \times \gamma(1 + \frac{1}{b})$$

γ = the value of the Gamma function

Figure 37 illustrates the Weibull curves for different shape factors assuming the location parameter 0. As we did not have sufficient data to estimate all parameters of the Weibull curve for the Montenegrin building stock, we made an assumption for a shape parameter of 2.5 and for a location parameter of 0. We assumed the lifetime of all building types constructed before 1945 as 120 years and the lifetime of all building types in other age categories as 100 years.

Using the Weibull curve and these assumptions we calculated the number of remaining buildings of each building type and in each age category until 2070. Applying assumptions about the number of dwellings per building made using data from the 2011 census

Figure 36 Key demographic indicators (2015 = 1.0)

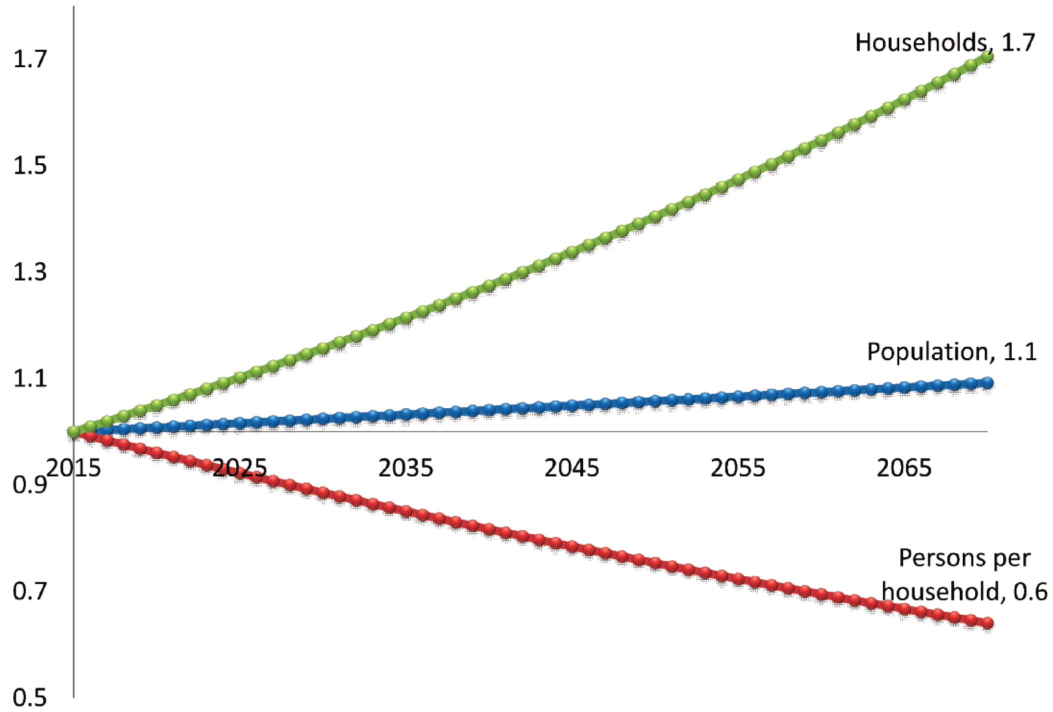
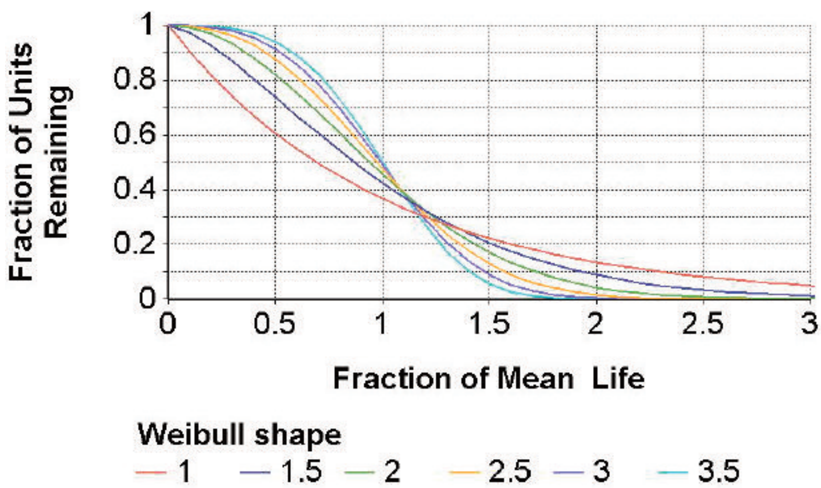


Figure 37 The Weibull curve (Welch and Rogers 2010)



(Monstat 2011), we also calculated the number of remaining dwellings in each building type and each age category until 2070.

Building stock habitation

In 2011, of the 24 percent of dwellings in Montenegro that were not inhabited, 3 percent were abandoned and 21 percent temporarily vacant. We excluded the abandoned dwellings from our model as they do not make an impact on the sector's energy consumption. In order to avoid overestimating energy consumption in buildings with temporarily non-inhabited dwellings, we introduced correction factors.

The share of temporarily vacant dwellings grew from 13 percent of dwellings in 2003, to 21 percent in 2011. The latter share of temporarily vacant dwellings is fairly common in Southern European countries, and we assume that it does not grow in the future.

It is not clear from the statistics how the temporarily vacant dwellings are distributed among buildings by type and age category. It is equally possible that a share of single-family houses or some apartments in multi-apartment buildings are temporarily vacant. When calculating the energy consumption in different segments of the building sector, we therefore applied the same factors to correct for habitation. This is an approximation, because the share of energy consumption of a partially inhabited multi-apartment building is not the same as the share of the inhabited dwellings in that building. However, a better approximation was not possible due to the unclear picture of the distribution of vacant dwellings.

Part 1 of the present book gives the number of non-inhabited dwellings by climate zone (see Section II, page 25). Based on these numbers and the total share of vacant buildings in the country, we assumed 0.77 as a correction factor for energy consumption in climate zone 1; 0.86 in climate zone 2; and 0.80 in climate zone 3.

Construction of new buildings and dwellings

We estimated the construction of dwellings as the gap between the demand for dwellings, represented by the number of households, and the remaining stock of existing dwellings. We assumed that the new dwellings have the same structure by building type as dwellings built during the last 15 years. New buildings are distributed by climate zone in the same way as existing buildings.

In order to calculate the building floor area in 2015–2070, we multiplied the remaining dwelling stock by the dwelling floor area by building age and type, as suggested by the building typology. For new dwellings we assumed the same floor area as for dwellings constructed during the last 15 years.

The annual construction rate was calculated as 1.4 to 1.5 percent of the residential building floor area between 2015 and 2030; 1.5 to 1.7 percent between 2030 and 2050; and 1.7 to 1.9 percent between 2050 and 2070.

Building floor structure in the future

We estimated that the building floor area in 2015 was 17.8 million m^2 and would reach 20.6 million m^2 in 2030; 25.0 million m^2 in 2040; and 30.2 million m^2 in 2070. The structure of the building floor area will change due to the demolition of old buildings and the construction of new buildings.

As Figure 38 shows, the share of the new building floor area will reach 19 percent of the total in 2030; 43 percent in 2050; and 64 percent in 2070. It is therefore important to ensure that new buildings comply with the existing building code. It is also important to tighten this code as soon as possible in order to avoid locking high energy consumption patterns into the long-term future. We can also conclude from the figure that a significant share of the building stock constructed after 1970 will remain in the medium- and long-term future. For this reason, it is essential to ensure that these buildings have a high energy performance after retrofitting.

The structure of the building floor area by building type is also expected to change in the future. As Figure 39 illustrates, the floor area of small buildings now represents, and will continue to represent over the modelling period, the highest share of the total floor area. Its share in the total floor area will, however, decrease, while that of large buildings will grow. Such a change is in line with the overall urbanisation trends in Montenegro. Moving to a city implies the likelihood of living in a multi-apartment building rather than a small house. This trend represents an additional challenge if the new, large buildings are not constructed according to high energy performance standards. The retrofitting of multi-apartment buildings is more difficult to stimulate than the retrofitting of small houses due to organisational barriers. In addition, options for retrofitting large buildings in urban areas to meet low-carbon standards are more limited than in rural areas.

Unfortunately, the 2011 census (Monstat 2011) did not provide a breakdown of the distribution of the building stock by building age and type, or by climate zone. Since only a breakdown of the total dwelling stock by climate zone is available (see Section II, page 25), we were not able to design any trends for the future and assumed that newly constructed dwellings will be distributed by climate zone in the same way as the existing dwelling stock.

Figure 40 presents the structure of the building floor area by building type and age — that is, the shares of the 18 representative buildings in the total building floor area — over the modelling period. Representative buildings with a share of more than 5 percent in the total area are included. The three biggest categories are small buildings constructed in 1971–1990, small buildings constructed in 2001–2015, and new small buildings (built after 2016). The significant age categories that represent more than 5 percent of building floor area in 2030 are small buildings constructed in 1946–1970, small buildings constructed in 1991–2000, large buildings constructed in 2001–2015, new large buildings (built after 2016), and large buildings constructed in 1971–1990.

Figure 38 Building floor area by building age category, 2015–2070

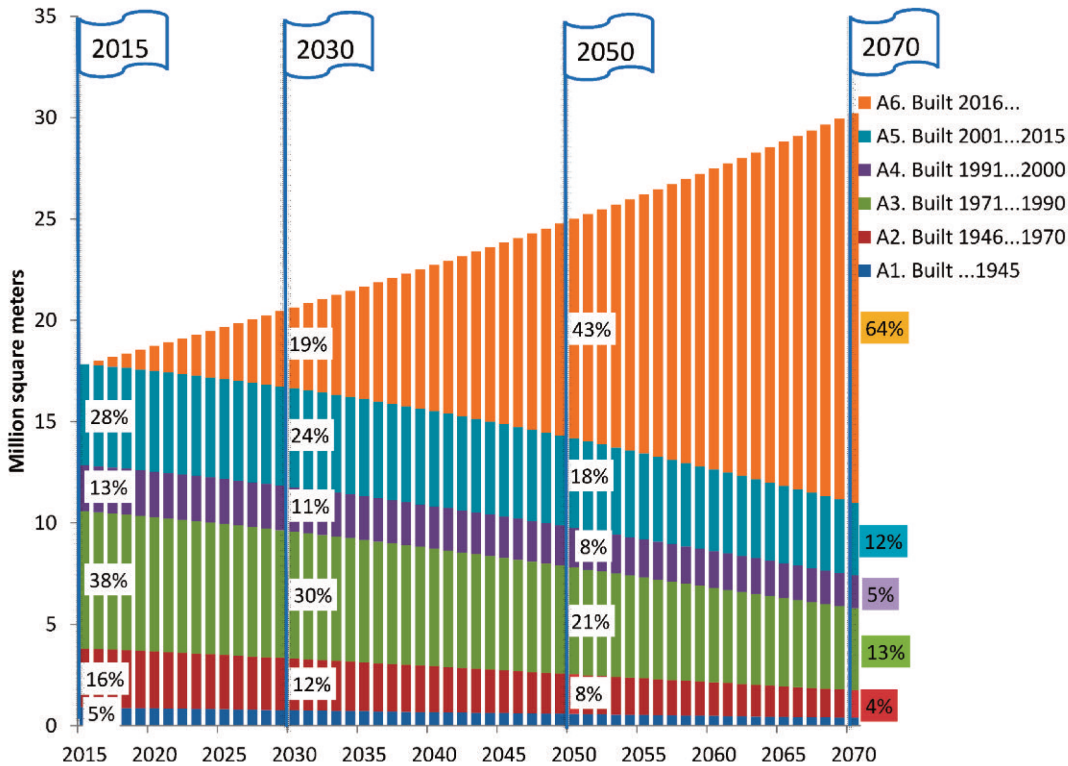


Figure 39 Structure of building floor area by building type, 2015–2070

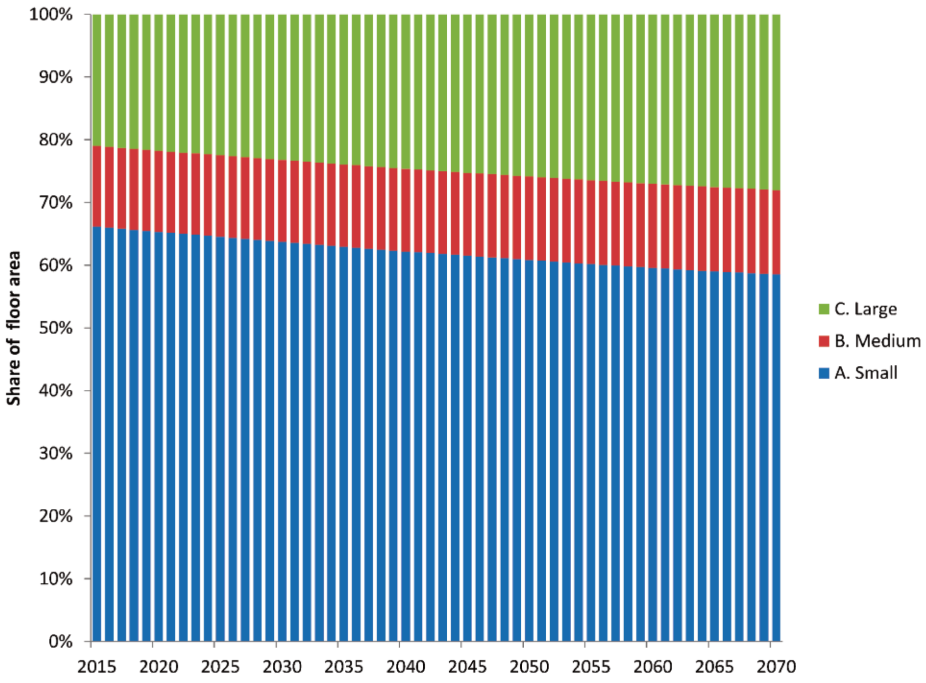
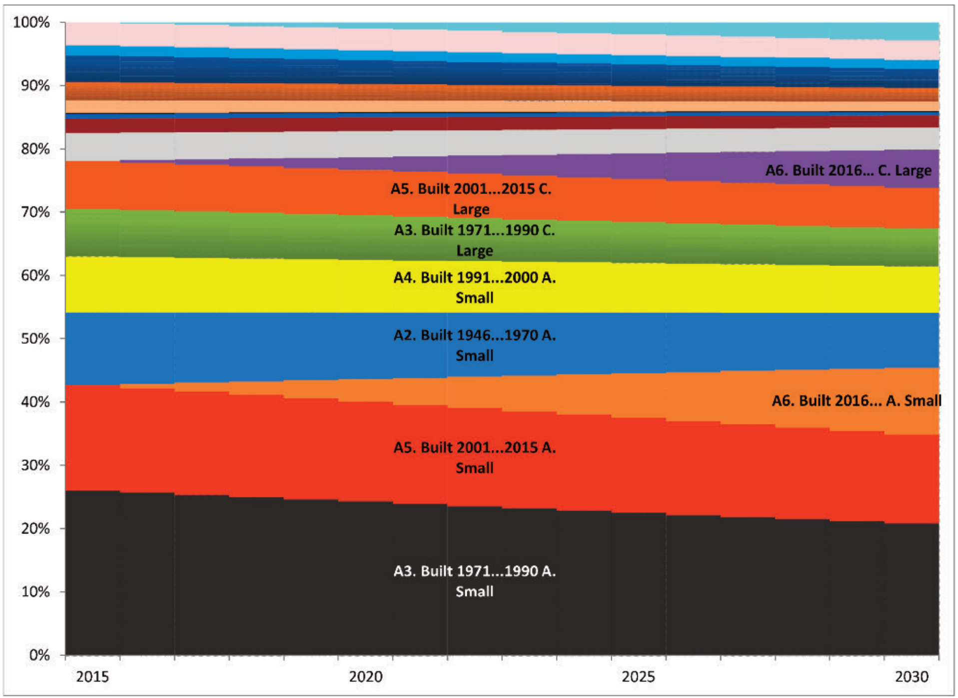


Figure 40 Structure of building floor area by building age and type, 2015–2030



VIII. Construction and calibration of the sector energy balance

The next step was to calculate final energy consumption at sector level in the base year (see Section III, page 45, for a definition of final energy consumption [delivered energy] at building level). Final energy consumption in each representative building in each climate zone was estimated as the sum of its final energy consumption for space heating, water heating and space cooling. We then multiplied the number of representative buildings by their final energy consumption in each climate zone and added up the results across all climate zones, building types and building age categories.

By way of a check, we compared the calculated final energy consumption at sector level with the sector energy balance available at the macro level. The latest (2013) energy balances for Montenegro published by Monstat (Monstat 2014b), EUROSTAT (EUROSTAT 2015) and the International Energy Agency (IEA online) clearly overestimates the share of residential buildings and clearly underestimates the tertiary sector in the structure of the "other" category in the country's final energy consumption. In other words, it is likely that a share of the tertiary sector is counted in the balance for the residential sector, and for this reason the official balances were not used.

On the recommendation of representatives from the Ministry of Economy, we compiled an estimate of the residential sector's energy balance in 2014 using two other sources. Thus, we oriented to the consumption of all energy sources except wood from the Energy Strategy of Montenegro, also known as the Green Book (Ministry of Economy 2013b). For data on wood consumption we relied on the wood consumption survey conducted by Monstat (2013). Since the survey was carried out in 2011, we corrected the data for 2014 assuming growth rates in wood consumption according to the Green Book. From the resulting balance we deducted a rough estimate for electricity use for lighting, appliances and cooking. The latter estimate was made based on the energy intensity for lighting, appliances and cooking in Croatian households (EEA 2012). The resulting balance represents the final energy consumption for thermal energy use. We refer to it as an estimated energy balance for our model, or simply as an estimated energy balance.

The calculated final energy consumption at sector level appeared significantly higher than the estimated sector energy balance. Based on consultation with national experts, we identified two main factors causing such a difference. First, households in Montenegro heat/cool their dwellings only partially, and second, they do not heat/cool their dwellings for the whole of the day.

With respect to the first factor, supporting results were obtained during a relatively recent survey on households that heat their dwellings using solid fuels (Monstat 2013). According to this survey, 44 percent of the dwelling floor area is heated in rural areas, and 52 percent in urban areas.

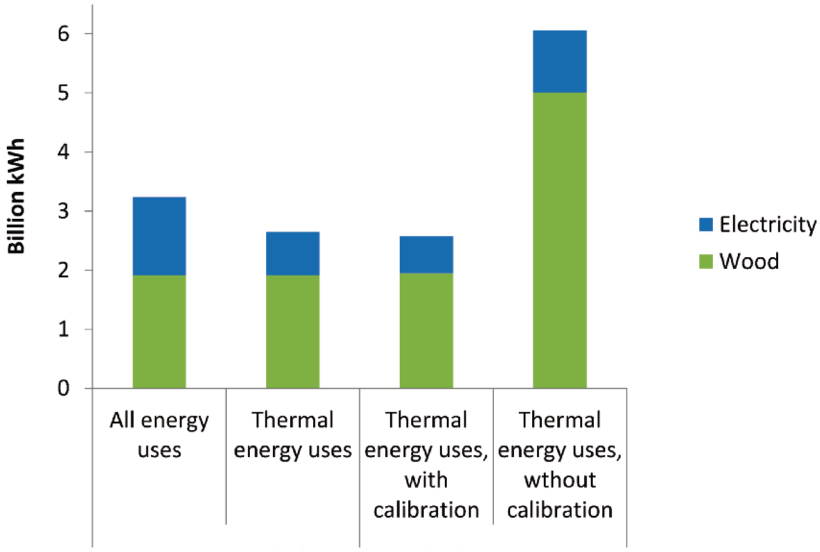
We could not find any evidence for the second factor, although there is universal agreement among national experts that the duration of heating/cooling is less than 24 hours. Households do not keep heating overnight and some households heat for only part of the day.

In summary, to correct the calculated final energy consumption for heating we assumed that 50 percent of the dwelling area is heated for 16 hours a day throughout the whole country in all building types. Similarly, we corrected the final energy consumption for cooling assuming that 50 percent of the dwelling floor area is cooled for around 12 hours a day.

During the calibration process we found that a share of Montenegrin households have double heating. They are likely to keep their traditional wood stoves for the coldest part of the year and heat their dwellings with electricity, usually heat pumps (air conditioners) when temperatures are moderate. For this reason, our model calculated the sector's final energy consumption based not on a breakdown of households using different energy sources for space heating, but on a breakdown of energy demand addressed by different energy sources in order to allow for more than one source of heating per household.

Figure 41 compares the estimated energy balance of Montenegro in 2014 and the calculated energy consumption for thermal energy uses with and without calibration to partial heating and duration of heating. The non-calibrated energy consumption is more than double the calibrated energy consumption or the estimated energy balance. This gap represents an important message for policy makers. If Montenegrin households heat the whole of the floor area of their dwellings throughout the entire day, the final energy consumption for thermal energy comfort would be at least double. As the standard of living of Montenegrin people will rise in the future, households will want to heat larger floor areas for longer periods of time. For this reason it is important to reduce the demand for energy by retrofitting existing buildings, to ensure the high energy performance of new buildings, and to install advanced technical systems as soon as possible in order to avoid a growth in energy demand due to rising living standards.

Figure 41 Sector energy balance and calculated final energy consumption, 2014



IX. Formulation of the reference and low-energy/low-carbon scenarios

In order to formulate the business-as-usual and low-energy/low-carbon-emission scenarios, we reviewed the barriers to the penetration of energy efficiency in the residential building sector in Montenegro, as well as existing, planned and potential relevant policies to overcome these barriers. The review presented is dated as of April 2015.

National policies prior to signing the Energy Community Treaty

In 2005, Montenegro adopted the Energy Efficiency Strategy (European Agency for Reconstruction 2005), which was implemented through regularly prepared action plans for energy efficiency. Although the action plans were not fully realised, certain positive trends were initiated (Legro, Novikova and Olshanskaya 2014). Despite the fact that the strategy was formulated 10 years ago, its priorities and key measures remain valid (Ministry of Economy 2005).

In 2007, Montenegro adopted the Energy Development Strategy of Montenegro up to 2025, which was updated in 2011. The new draft is referred to as the White Book (Ministry of Economy 2014). The Energy Strategy is a strategic document for the development of the country's energy sector and energy policy, including energy efficiency policy.

Commitments under the Energy Community Treaty

Becoming a contracting party to the Energy Community Treaty prompted the adoption of many energy efficiency policies in Montenegro. In accordance with the treaty, the country has made a commitment to adopt the EU energy acquis, including energy efficiency legislation. The commitment includes the transposition of the following directives:

- The Energy Performance of Buildings Directive (EPBD) 2010/31/EC by September 30, 2012 (European Commission 2010b)
- The Directive on the Indication by Labelling and Standard Product Information of the Consumption of Energy and Other Resources by Energy-Related Products (Energy Labelling Directive) 2010/30/EU, as well as a set of implementing directives/delegated acts, by December 31, 2011 (European Commission 2010a)
- Directive 2006/32/EC on Energy End-Use Efficiency and Energy Services (Energy Services Directive, or ESD) by December 31, 2011 (European Commission 2006)
- The Energy Efficiency Directive (EED) 2012/27/EU by September 30, 2016 (European Commission 2012)

Even though Directive 2009/125/EC on Eco-design Requirements for Energy-Using Products (Ecodesign Directive, European Commission 2009) is also included among the EU's energy efficiency legislation, the Energy Community Treaty does not require its transposition. The EED amended the Labelling and Eco-design directives and replaced the ESD, with the exception of Article 4, which remains in force.

In addition to the EU legislation directly linked to energy efficiency in buildings, legislation that regulates energy prices paid by final consumers has an indirect impact on energy efficiency. According to the guidelines on the reform of regulated electricity prices in the Energy Community (Energy Community Secretariat 2012), contracting parties had to ensure as of July 31, 2013, that regulated electricity prices for all customers, including households, are cost-reflective. The reform of other energy markets is expected in future phases.

Implementation of the Energy Services Directive

In 2010, Montenegro introduced the framework Law on Energy Efficiency (Republic of Montenegro 2010), which transposed the Energy Services Directive 2006/32/EC. The law is implemented by a package of by-laws, establishing, among other things, the methodology for setting the indicative energy-saving target in 2018 and the adoption of national energy efficiency action plans (NEEAPs). The new Law on the Efficient Use of Energy was adopted in December 2014 (Republic of Montenegro 2014) in order to further improve the implementation of EU energy efficiency legislation, including the ESD.

The first Montenegrin NEEAP for the period 2010–2012 was adopted in 2010 (Ministry of Economy 2010). In 2012, the Ministry of Economy published a report on the implementation of the first NEEAP for

2011 (Ministry of Economy 2012). The second Montenegrin NEEAP for the period 2013–2015 was adopted in 2013 (Ministry of Economy 2013a) and is recognised as the country's main document on energy efficiency. The second NEEAP also includes an assessment of the implementation of the first NEEAP. According to the first and second NEEAPs, policies and measures implemented in the residential building sector include:

- information campaigns and networks of energy efficiency information centres;
- the energy labelling of household appliances;
- financial support to citizens (low-interest loans) for investments in solar thermal systems and modern stoves running on biomass;
- individual metering and informative billing for residential consumers;
- the development and preparation of a regulatory framework for energy efficiency in buildings;
- the implementation of regular energy audits of heating systems and air-conditioning systems;
- energy performance certification of buildings; and
- strengthening education on energy efficiency.

Implementation of the Energy Performance of Buildings Directive

In 2010, the Law on Energy Efficiency (Republic of Montenegro 2010) transposed the EPBD 2002/91/EC. Among other things, the law requires energy efficiency building codes for new buildings as well as for existing buildings at the point of renovation. It also requires energy audits of buildings larger than 1,000 m^2, energy audits of boilers and air-conditioning systems, and building certification. The body of secondary legislation — that is, a set of rulebooks — was adopted in 2013 and includes:

- minimum energy efficiency requirements in buildings (23/2013);
- the energy performance certification of buildings (23/2013);
- a methodology for performing energy audits of buildings (23/2013);
- a training programme for energy audits (24/2013); and
- regular energy audits of air-conditioning and heating systems (24/2013).

The new Law on the Efficient Use of Energy, approved in 2014 (Republic of Montenegro 2014), transposed the EPBD 2010/31/EU. In addition, the Law on Spatial Planning and Construction, amended in 2013, introduced provisions dealing with the energy efficiency requirements to be fulfilled during the development of spatial/urban plans. It also requires designers to calculate the energy performance of new buildings when they prepare the specific technical documentation (Energy Community Secretariat 2014).

According to the EPBD requirements, the Ministry of Economy plans to develop a building stock inventory and define reference buildings, develop national software for energy performance calculation and building certification, and provide further education and capacity building (Energy Community Secretariat 2014).

Implementation of the Energy Efficiency Directive

The Law on Energy Efficiency (Republic of Montenegro 2010) transposed several requirements of the EED. Its implementing by-laws are:

- The Instruction on Determining the Methodology for the Calculation of the Indicative Energy-Saving Target (OG 18/11)
- The Decision on Determining the Indicative Energy-Saving Target (OG 48/201)
- The Rulebook on Determining the Limit for Energy Consumption to Define Big Consumers, the Content of the Energy Efficiency Improvement Plan and the Report on Plan Implementation (OG 10/12)
- The Rulebook on the Information System for Energy Consumption and on the Manner of Submitting Data on the Annual Consumption of Energy (OG 6/12)
- Instructions on Energy Efficiency Measures and Guidelines for their Implementation (OG 51/2012)

The new Law on the Efficient Use of Energy (OG 29/10) (Republic of Montenegro 2014) includes provisions from the EED 2012/27/EU on:

- measuring energy consumption;
- the energy performance of buildings;
- energy audits of buildings and systems;
- the certification of buildings;

- the further education of providers;
- the building inventory; and
- energy services.

Implementation of the Energy Labelling Directive

In 2010, the Law on Energy Efficiency (Republic of Montenegro 2010) transposed the requirements of the previous Directive 92/75/ EEC, although not the recast Labelling Directive 2010/30/EU and the delegated acts. The Law on the Efficient Use of Energy (Republic of Montenegro 2014) and the draft Rulebook on the Labelling of Energy-Related Products include provisions for the implementation of the Labelling Directive.

Implementation of the Eco-design Directive

Although the transposition of the Eco-design Directive is not required, Montenegro is working on it voluntarily. In 2010, the Law on Energy Efficiency (Republic of Montenegro 2010) transposed the requirements of the previous Eco-design Directive. The draft Regulation on the Eco-design of Energy-Related Products, which includes three groups of products, was prepared for adoption as of November 2014.

Implementation of energy pricing reform

Electricity and natural gas pricing in Montenegro currently excludes environmental and energy taxes (Singh, Limaye and Hofer 2014). From 2015, households are able to switch their electricity providers (Energy Community Secretariat 2014). The electricity generation price still has to be deregulated and no significant annual increase is envisioned (Singh, Limaye and Hofer 2014).

The law also defines vulnerable customers and obliges the government to provide financial support for their protection. Special tariffs for vulnerable customers were regulated by the Energy Regulatory Authority until July 2015 (Energy Community Secretariat 2014).

Energy efficiency financing

In 2006, the Fund for Energy Efficiency was established within the budget of the Ministry of Economy. The fund operates projects supported by the state budget, donors, loans and their financing mechanisms (Energy Community Secretariat 2014).

According to Article 47 of the Law on Energy Efficiency, energy efficiency projects and measures may be financed from the public budget of Montenegro, local self-governing unit budgets, donations, loans and other financial sources.

Summary of barriers as well as existing, planned and relevant policies

Table 27 presents a brief summary of existing barriers to energy efficiency penetration in residential buildings in Montenegro, and policies aimed at overcoming them. Policies labelled “E” are existing policies — that is, policies that have already been elaborated, adopted and implemented. Policies that are currently being planned and adopted according to the requirements of the EU energy acquis are marked “P”. Finally, policies required for the transposition and implementation of the EU acquis but not yet planned, as well as additional feasible policies, are labelled “F”.

The summary was prepared based on a review of existing barriers to energy efficiency penetration (Singh, Limaye and Hofer 2014; Ryding and Seeliger 2013; Legro, Novikova and Olshanskaya 2014); the commitments of Montenegro as a contracting party to the Energy Community Treaty, as discussed above; existing and planned policies in Montenegro, also discussed above; and policies recommended in the literature (Lucon et al. 2014; Ürge-Vorsatz et al. 2012; Bürger 2012; Ryding and Seeliger 2013; Singh, Limaye and Hofer 2014).

Table 27 Policies in the residential building stock in Montenegro tailored to the main barriers (as of April 2014)

Households:	that are not interested in thermal retrofitting		that are interested in thermal retrofitting		that are undergoing thermal retrofitting	
Barriers	**Barriers**	**Policy**	**Barriers**	**Policy**	**Barriers**	**Policy**
All types of dwellings						
Market failures: Imperfect information	Lack of knowledge, attention, interest	Information campaigns (E), energy tariff reform (P) and taxation, detailed bills (P), free mini-audits (F), building codes (E), appliance standards (P), obligations to retrofit (F)	Lack of practical knowledge and skills in technical/financial analysis	Detailed bills (P), building codes (E), appliance standards (P), building certification (E), appliance labelling (P), desk advice (E), comprehensive audits (E)	Lack of reliable technical advice	Comprehensive audits (F), desk advice (E)
Behavioural barriers	Ignorance of benefits	Information campaigns (E), energy tariff reform (P) and taxation, detailed bills (P), free mini-audits (F), building codes (E) and appliance standards (P), obligations to retrofit (F)				
	Culture, tradition					
Financial barriers			High discount rates for households	Concessionary loans (E), grants (F), tax incentives, obligation to retrofit at point of general renovation (F)		
			High up-front costs			
			Lack of access to capital	Concessionary loans (E)		
			High cost of capital from lenders	State guarantees to banks (F)		
			Unwillingness to incur debts	Tax incentives		
			No rise in property sales price and uncertain resale after retrofitting	Building certification (E), obligation to retrofit at the point of transaction (F)		
	Regulated price of energy, lack of internalisation of external costs			Tariff reform (P), energy taxation		
	Heating tariffs linked to the living floor area			Consumption-based billing for heating (P)		
Hidden costs and benefits	Information search costs	Information campaigns (E), detailed bills (P), free mini-audits (F), building certification (P), appliance labelling (P)	Costs of searching for the right option	Free mini-audits (F), desk advice (E), subsidised comprehensive audits (E)	Costs of searching for installation advice	Free mini-audits (F), desk advice (E), subsidised comprehensive audits (F)
			High transaction costs due to small size	Project bundling by ESCOs		
Project bundling by ESCOs	Low level of implementation and enforcement of policies			Capacity building (P), education and training (P), integration with other policies (F)		
			Unstable financing of programmes	Back-up of state programmes with other sources (P), raising finance from commercial banks (P)	Lack of skilled providers	Apprenticeship (E), master training (E), further education (P), accreditation of contractors through branded quality standards (F)
Market failures: Technological risks					Lack or low quality of technologies	Building codes (E) and certification (E), product standards and labelling (P)
					Risk of failure, heterogeneous retrofitting outcomes	Quality standards (F), qualified retrofitting plans (F)
Rented dwellings						
Organisational barriers			Landlord–tenant dilemma	Cost and benefit allocation rules between tenants and landlords (F), rent reduction claims of tenants in case retrofitting not carried out by landlords		
Dwellings in multi-dwelling buildings						
Organisational problems			Collective decision problems	Obligation to retrofit at point of general renovation (F)		
			Access to capital	Requirement for homeowner associations to establish retrofitting funds (F)		
			Low creditworthiness of homeowner associations	State guarantees for commercial banks (F)		
Illegal dwellings						
Behavioural barriers			Disregard for construction rules	Legalisation of dwellings (P)		
Financial barriers			No eligibility for finance	Grants and concessionary loans (F)		
Low-income households						
Financial barriers			Lack of capital	Grants (F), state guarantees for commercial banks (F)		

Notes: E – adopted and implemented policies; P – policies being planned and adopted according to the EU acquis; F – policies required under the EU acquis but not yet planned, and additional feasible policies

Assumptions and policy package in the reference scenario

In the reference scenario we assumed business-as-usual technological, policy and market changes. We assumed that existing buildings are retrofitted at least once during their lifetime. Since the lifetime of buildings constructed before 1945 is about 120 years, and the lifetime of the remaining existing buildings is 100 years, it was assumed that retrofitting occurs on average 55 years after the building was constructed. In other words, the business-as-usual retrofitting rate is 1/55 or 1.82 percent per year.

We estimated that, after the business-as-usual retrofitting, building energy demand decreases by 20 percent. According to the building code in force, existing buildings that undergo major renovation also have to comply with building code requirements. The majority of business-as-usual retrofits, however, are not major renovations, which is why it is unlikely that the building code will have a significant direct impact on them.

In some dwellings that are retrofitted in the business-as-usual case, heating systems are also replaced. It is assumed that, after retrofitting, the shares of energy sources for space heating in existing buildings constructed before the year 2000 will be the same as the shares in buildings constructed during the last 15 years. We also assumed that all households that undergo retrofitting start using space cooling.

The business-as-usual retrofit assumes the improvement of thermal comfort in dwellings. As a result, households will increase the share of heated floor area from 50 percent to 65 percent and will heat for one hour longer per day than before. No increase was assumed in the share of floor area cooled or the duration of space cooling.

New buildings are constructed according to the building code introduced in 2013. The requirements envisioned by the building code correspond to the characteristics of the measures in standard improvement 1. In addition, the share of the living area heated/cooled and the duration of heating/cooling are higher than previously. We assumed that households would heat 80 percent of the dwelling area for at least 18 hours per day; and that households would use space cooling for 55 percent of their dwelling area for at least 14 hours a day. The breakdown of energy sources for space and water heating in new buildings was assumed to be the same as for existing buildings built during the last 15 years.

It is likely that some buildings will undergo retrofitting more than once during their lifetime. However, we considered only the first retrofitting, starting from the present moment, over the modelling period.

Assumptions and policy packages in the SLED moderate and ambitious scenarios

Policy tools for energy efficiency improvement are often classified into regulatory tools, fiscal/financial incentives, market-based tools and information tools (Ürge-Vorsatz et al. 2012). The regulatory group of tools, which includes construction and renovation norms or building codes, has proved to be the most effective and cost-effective (*ibid*.). However, EU experience shows that building codes are not sufficient to reduce energy consumption in existing buildings at the desired rate. A comprehensive package of policy tools, consisting of "carrots", "sticks" and "tambourines", should therefore be adopted to tackle this challenge.

Our policy packages explicitly model the impact of regulatory policy tools and financial incentives ("sticks" and "carrots"). The impact of "tambourines", or information policies, is difficult to model explicitly using a bottom-up approach. For this reason, information policies are assumed to be included into our policy package as one of its success factors. The designed packages are simulated packages, rather than the best or optimal packages, and indicate the level of effort required in order to achieve the low-energy and low-carbon transformation of the building sector.

Our policy packages were formulated in accordance with EU energy efficiency legislation. The packages are aimed at a transformation to a more efficient building stock in the future, as outlined in the EU Energy Roadmap 2050 (European Commission 2011a). We assumed two levels of ambition for this transformation. According to the first level of ambition, it was assumed that by 2070 all new and existing buildings would achieve at least the level of standard improvement 1, defined in Part 1. The second level of ambition assumes that by 2050 the majority of new and existing buildings will achieve the level of ambitious improvement 2, also defined in Part 1. We refer to the policy package corresponding to the first level of ambition as the SLED moderate scenario; and the policy package corresponding to the second level of ambition as the SLED ambitious scenario.

Figure 42 illustrates the SLED moderate scenario, according to which Montenegro has no new regulatory policies and financial support schemes for new buildings, other than the building code currently in force.

In order to ensure the retrofitting of the entire existing building stock, we assumed that in the SLED moderate scenario all buildings remaining until 2070 would be retrofitted at least once to the level of improvement 1. The improvement implies not only lower energy consumption, but also greater comfort. The heated floor area will be increased to 80 percent, and dwellings will be heated for at least 18 hours. The cooling floor area will increase to 55 percent and the duration of cooling will remain at 14 hours a day.

To ensure the implementation of these retrofits, we assumed that Montenegro would introduce financial incentives for investors in the residential sector. Households in small buildings face lower organisational and legal barriers to obtaining investment capital than households in medium-sized and large buildings, thus for the majority of households in small buildings the introduction of low-interest loans is relevant. For households in such houses that are considered to have a low income, we suggest the introduction of grants. We assumed that the share of low-income households would be 10 percent of the total households.

We also assumed that only 10 percent of households in medium-sized and large buildings would be able to overcome the organisational barriers and obtain low-interest loans for building retrofits; and that the remaining households in these buildings would thus be eligible to obtain grants. As the market cumulates experience of providing loans for retrofits in medium-sized and large buildings, the share of households that are able to obtain loans will grow to 90 percent by 2050. For the remaining households that are considered to have a low income, the government will continue to provide grants.

Figure 43 illustrates the SLED ambitious scenario, according to which we assumed that, in addition to the 2013 building code, Montenegro would introduce a more stringent building code in 2022. The requirements envisioned by the building code correspond to the characteristics of the measures in ambitious improvement 2. Up until 2022, the previous building code is in force.

In order to prepare the market for the new, more ambitious building code, in 2016 Montenegro introduces low-interest loans for new buildings with characteristics corresponding to the measures in improvement 2.

Figure 42 The policy package in the SLED moderate scenario

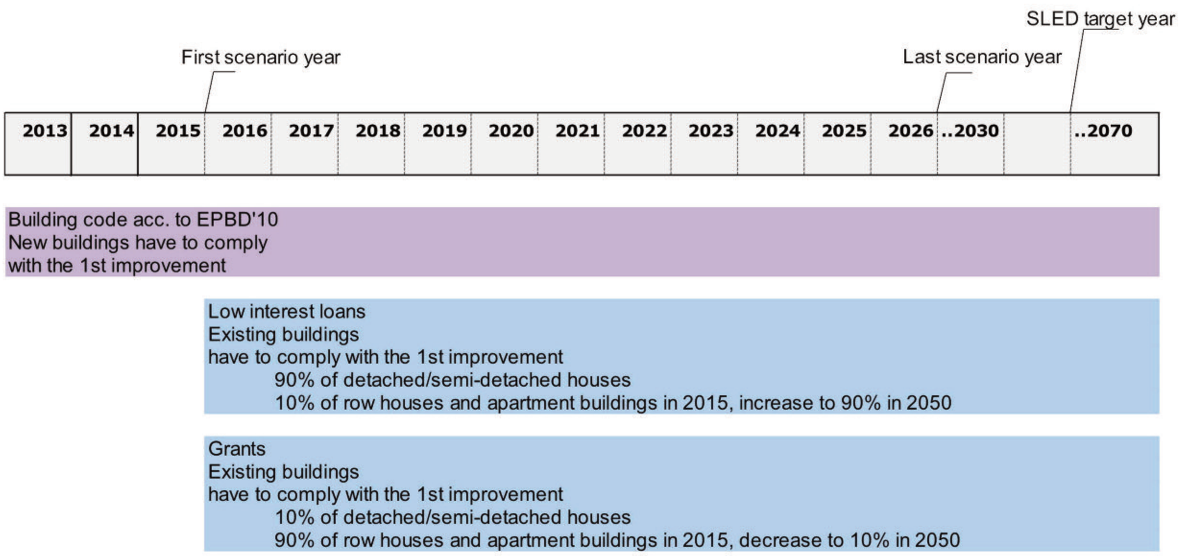
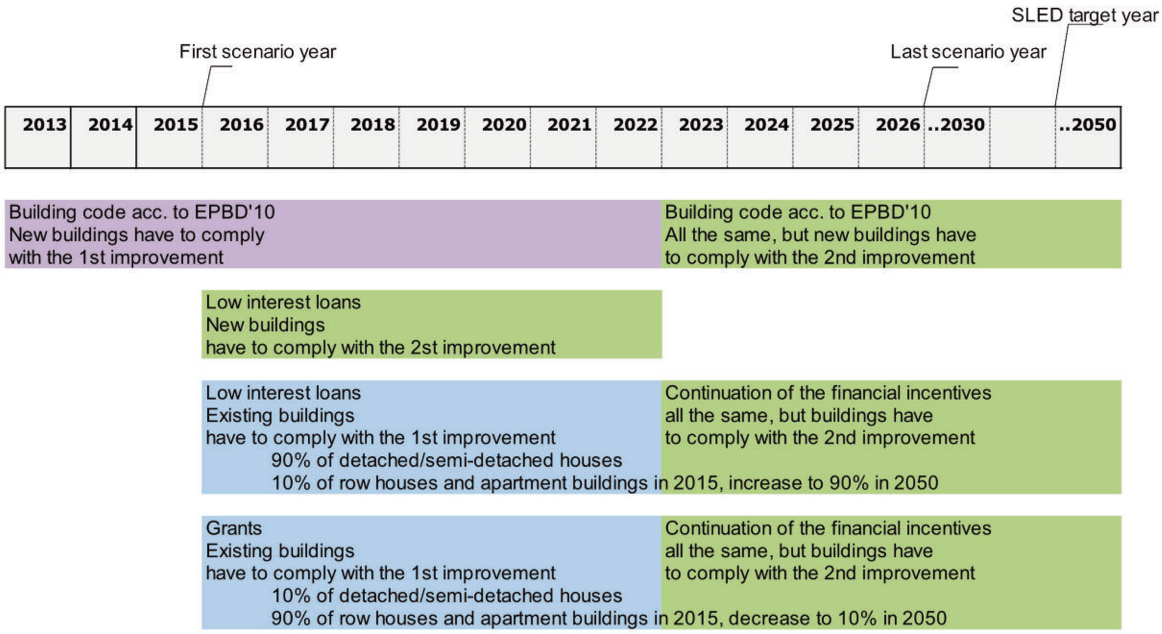


Figure 43 The policy package in the SLED ambitious scenario



Similar to the SLED moderate scenario, in the SLED ambitious scenario we assumes that all buildings remaining until 2050 would be retrofitted at least once. The retrofitting will be carried out according to improvement 1 until 2022, and according to improvement 2 from 2023 up to 2050. Improvement 2 implies even greater thermal comfort. The share of heated floor area will be increased to 100 percent, and dwellings will be heated for 18 hours. The share of cooled floor area will be 60 percent, and the duration of cooling will increase to 16 hours a day.

Likewise, in order to ensure the implementation of these retrofits, we assumed that Montenegro would introduce financial incentives for investors in the residential sector. Up until 2022, financial incentives would be provided in order to achieve a level of performance according to improvement 1; and between 2023 and 2050, the incentives would be provided in order to achieve a level of performance according to improvement 2. The structure of the financial incentives would be the same in the SLED moderate and ambitious scenarios.

We assumed that all new buildings would comply with the requirements of the building code in both scenarios, ensured by the approval of construction plans ex-ante and the issuing of building performance certificates ex-post. Similarly, we assumed that low-interest loans for new, efficient buildings, as well as low-interest loans and grants for retrofits, would be provided according to the same conditions.

X. Reference scenario: Results

Final energy consumption

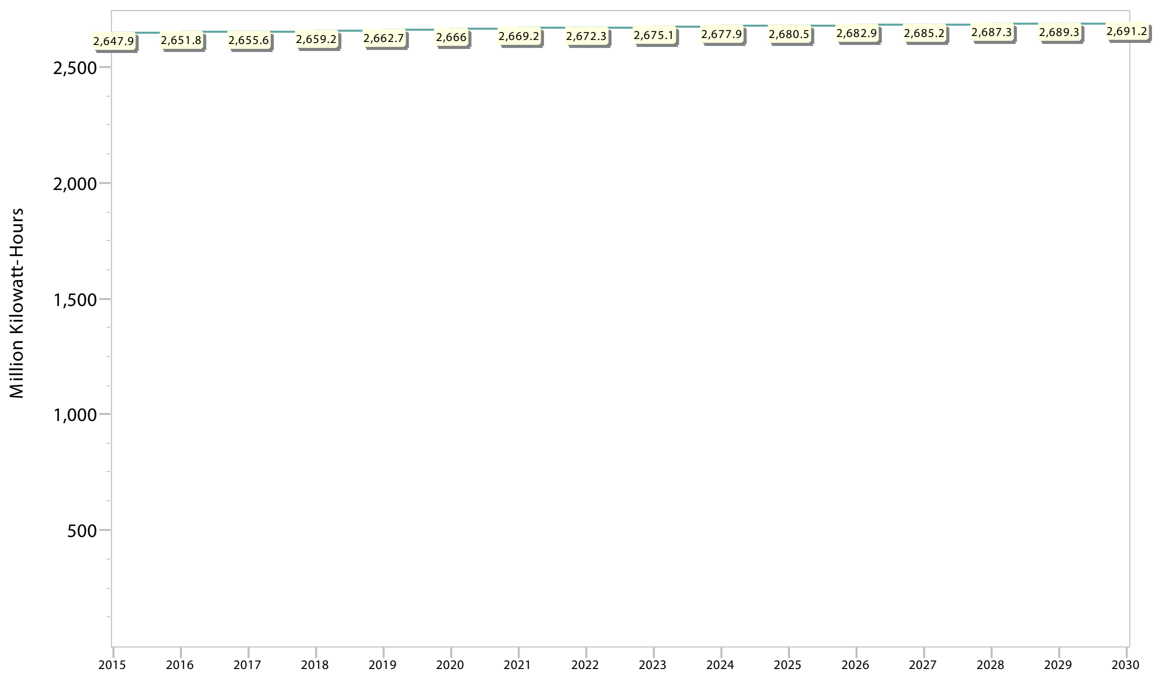
Figure 44 shows that, in 2015, final energy consumption in the residential sector for thermal energy services was 2.6 billion kWh. Final energy consumption will grow by around 2 percent over the modelling period, reaching 2.7 billion kWh in 2030.

Figure 45 shows final energy consumption by energy source. In 2015, it comprised 24 percent electricity and 76 percent wood. The figure shows that there will be no significant changes in the levels of consumed electricity and wood. While some existing dwellings and new large buildings will switch to more electrical heating, as described in the assumptions for the reference scenario, wood will more often be used in new small and medium-sized buildings. These two factors will balance the contribution of these energy sources to the final energy consumption.

Figure 46 shows final energy consumption by building age category. The figure shows that final energy consumption in existing buildings is expected to decline, due to the fact that a share of existing buildings will be demolished by 2030. While the business-as-usual improvement of existing buildings implies a 20 percent reduction in net energy demand, this saving is offset by a higher level of thermal comfort.

A comparison of this figure with Figure 38 (page 70), which shows the structure of the building floor area by building age category, suggests the priorities for improving energy efficiency in residential buildings. While buildings constructed between 1970 and 1990 occupy 32 percent of the building floor area in 2030, they contribute 40 percent to the total final energy consumption and are therefore a clear priority for policy intervention. New buildings will be responsible for 10 percent of final energy consumption in 2030, even though their floor area will represent 19 percent of the sector total. This estimate is made assuming that new buildings comply with the building code introduced in 2013. If they do not, and are built in line with the practices typical of the previous 15 years, then their share in the final energy consumption will be far greater. For this reason, policies ensuring that new buildings comply with the building code are also important. It is far easier to regulate building energy performance at the point of planning and construction, than it is to incentivise the retrofitting of new buildings at a later date.

Figure 44 Final energy consumption in the reference scenario, 2015–2030



We found that the breakdown of final energy consumption by building type will stay almost the same over the modelling period. Although the structure of the floor area will change towards a greater share of large buildings (Figure 39), the share of these buildings in final energy consumption does not increase because energy demand per square metre in these buildings is lower than in small buildings. As Figure 47 shows, 83 percent of final energy consumption for thermal energy uses will originate in small buildings between 2015 and 2030. Medium-sized and large buildings will account for 8 percent and 9 percent of final energy consumption respectively. This distribution of final energy consumption by building type suggests that small buildings are a clear priority for policy making.

Figure 48 shows final energy consumption in the residential sector by building age and type over the modelling period. The largest share in final energy consumption (34 percent) will originate in small buildings constructed in 1971–1990. Even if this category is split by decade, it still represents a very large share in final energy consumption. Small buildings constructed in 2001–2015, 1946–1970 and 1991–2000 are also responsible for big shares (over 10 percent) in final energy consumption in 2030. This clearly suggests the key building categories to which standardised approaches to building efficiency improvements, and thus policies, can be applied.

Figure 49 illustrates the distribution of final energy consumption by climate zone. Our analysis, assuming the same distribution of the future building stock as at present, suggests that even though 61 percent of the building floor area will be located in climate zone 1 in 2030, only 50 percent of the final energy consumption will originate in this climate zone because of the relatively mild climate. By contrast, the 27 percent of floor area located in climate zone 3 will be responsible for 34 percent of final energy consumption due to the lower temperatures there. The remaining 13 percent of floor area located in climate zone 2 will be responsible for 17 percent of final energy consumption.

Figure 50 shows the final energy consumption broken down by energy use. Space heating will occupy the biggest share in final energy consumption in 2030, while water heating and space cooling will be responsible for 17 percent and 3 percent of final energy consumption respectively.

Figure 45 **Final energy consumption by energy source in the reference scenario, 2015–2030**

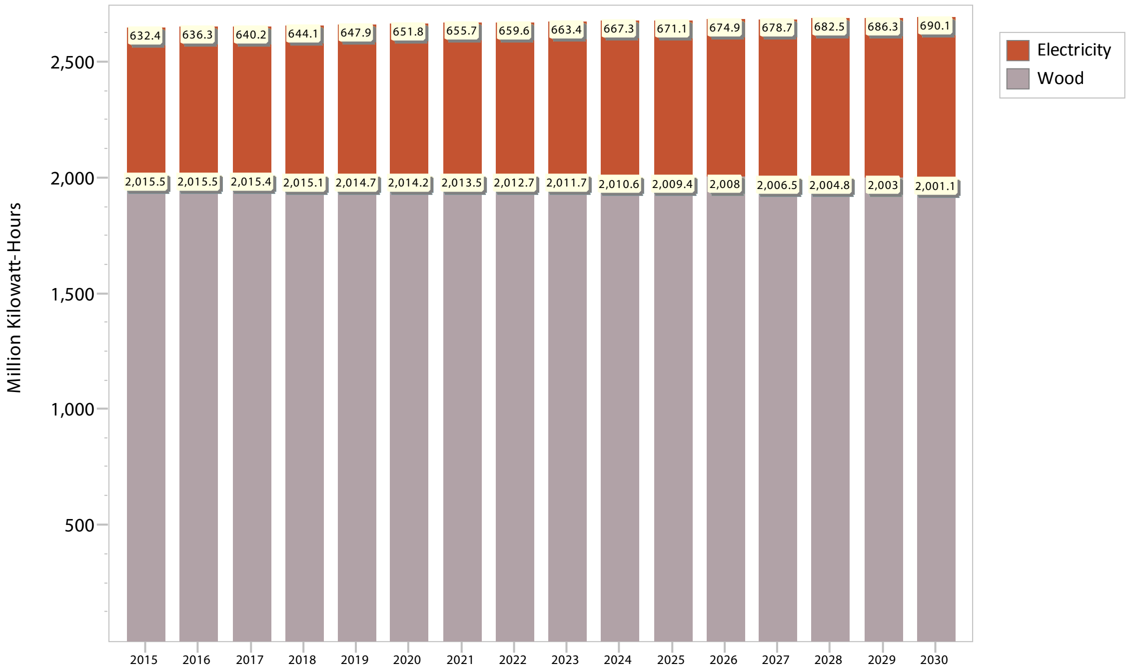


Figure 46 Final energy consumption by building age category in the reference scenario, 2015–2030

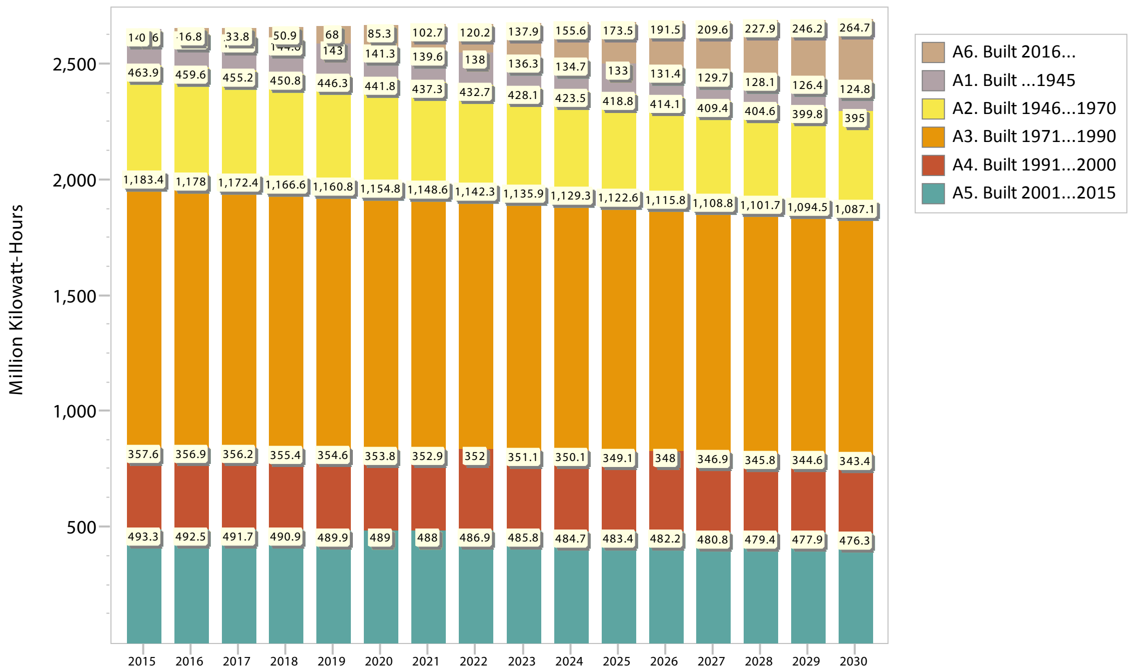


Figure 47 Final energy consumption by building type in the reference scenario, 2030

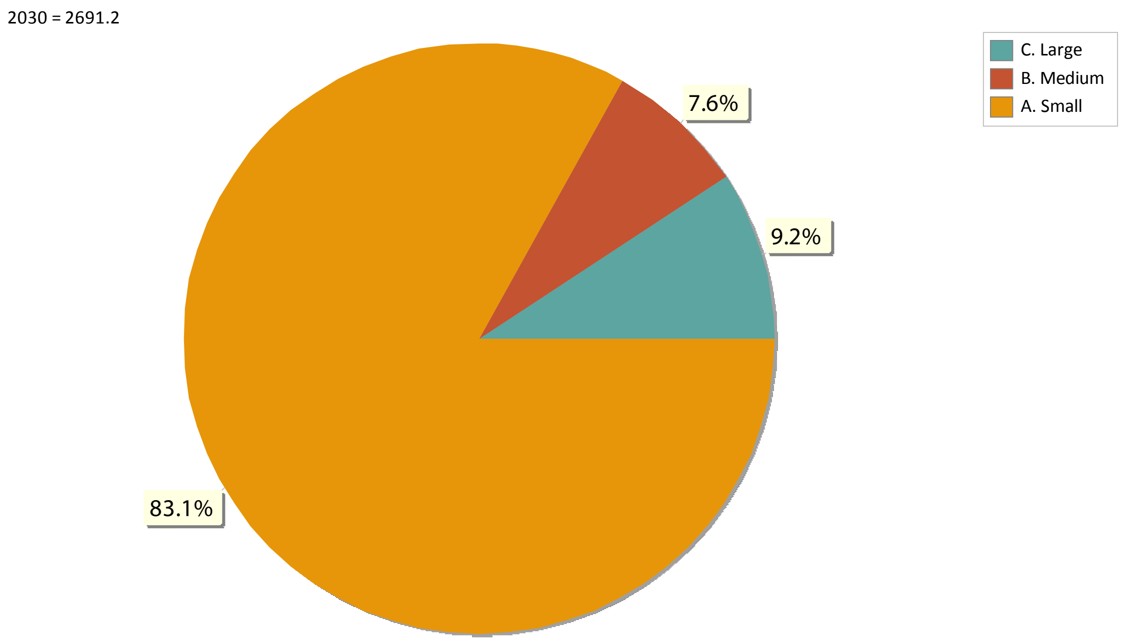
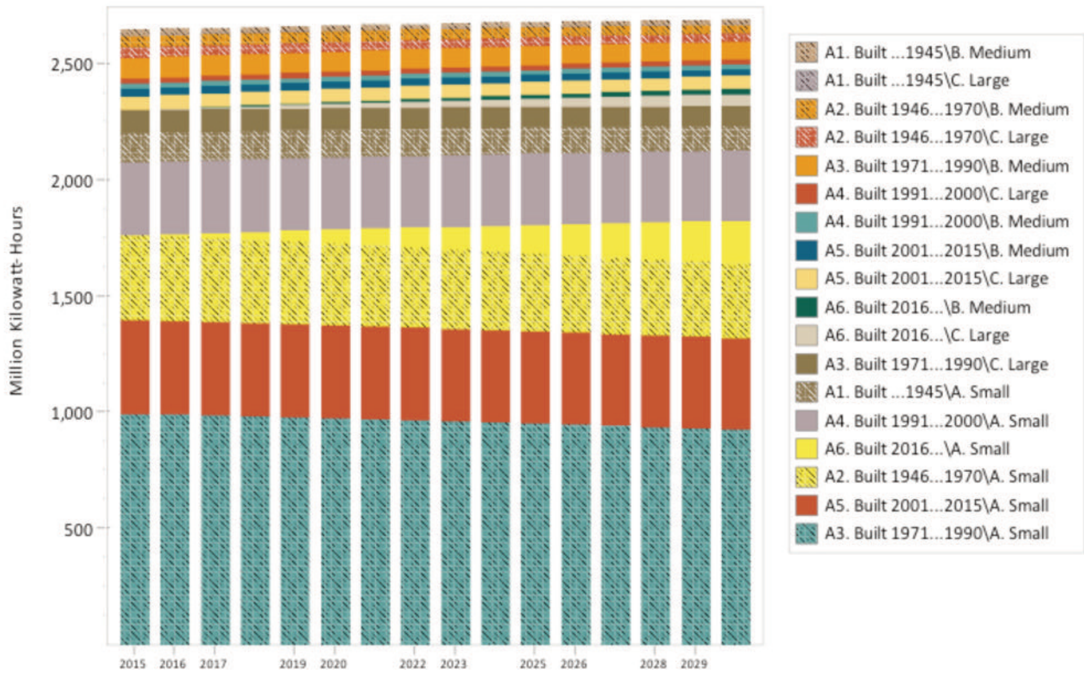


Figure 48 Final energy demand by building age and type in the reference scenario, 2015–2030



CO_2 emissions

Figure 51 shows the trends in CO_2 emissions associated with the residential building stock. Since the emission factor for wood, assumed on the basis of the IPCC guidelines, is 0 (IPCC NGGIP online), emissions from wood combustion are zero. Energy sources used for thermal energy services other than electricity and wood are too insignificant to be included in our model, thus these emissions are also zero in the model. The only energy source responsible for CO_2 emissions in the residential building sector is thus electricity. According to the IPCC guidelines, CO_2 emissions from electricity are accounted in the transformation sector. However, since electricity is consumed in residential buildings, these emissions originate indirectly from this sector.

In 2015, the sector emitted 365,000 tonnes of CO_2 emissions associated with electricity consumption. Even though electricity consumption is expected to increase up to 2030, the associated CO_2 emissions will decline over this period due to the decreasing emission factor. In 2030, they will be 60 percent of their 2015 level.

Energy costs

Based on a report by our national consultants (see Section V, page 55), the current price of electricity for residential consumers is EUR 0.1/kWh. We assumed that in 2020 this price would, in addition, include the average support for renewable energy sources, as suggested by the SLED electricity decarbonisation model (Szabó et al. 2015).

From 2021, we assume an increase in the electricity price following Montenegro's accession to the EU. In 2012, as an EU average, taxes and network costs accounted for 58 percent of the electricity price for households, while energy and supply costs accounted for the remaining 42 percent (European Commission 2014). The share of taxes and network costs continues to grow. If Montenegro replicates this tendency once part of the EU, the electricity price will also rise. We assumed that, by 2030, the share of taxes and network costs in the electricity price would be around 42 percent — that is, in line with the current EU level. Such assumptions represent a 2 percent per year electricity price increase between 2020 and 2030. In summary, the electricity price for residential

Figure 49 Structure of final energy consumption by climate zone in the reference scenario, 2030

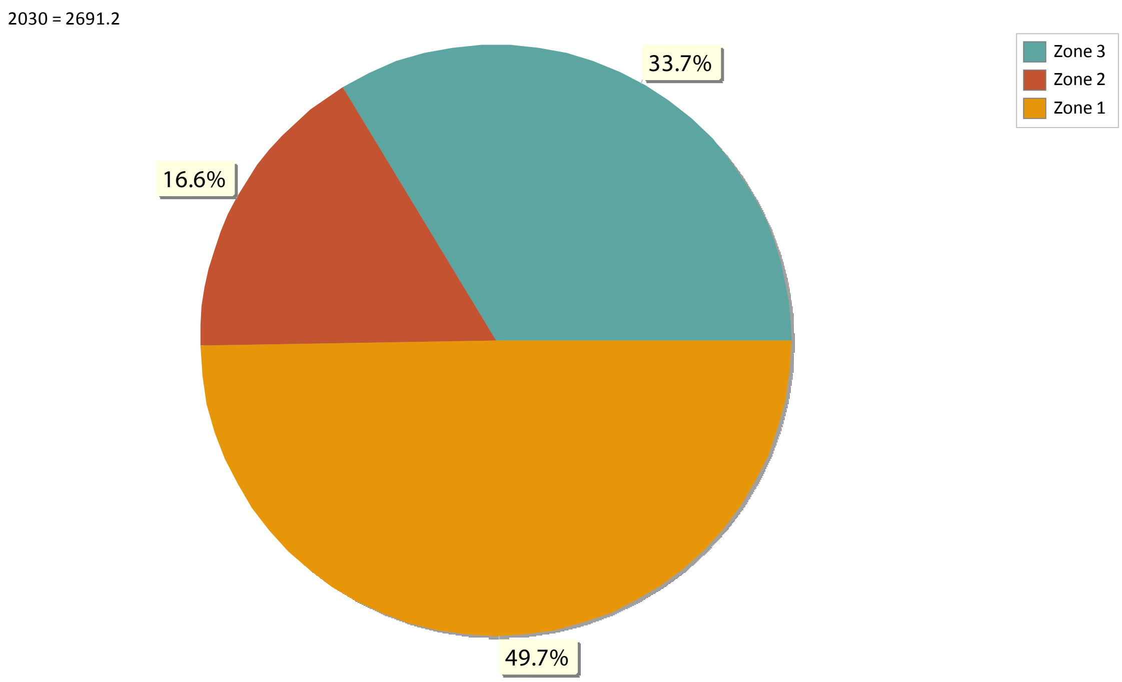
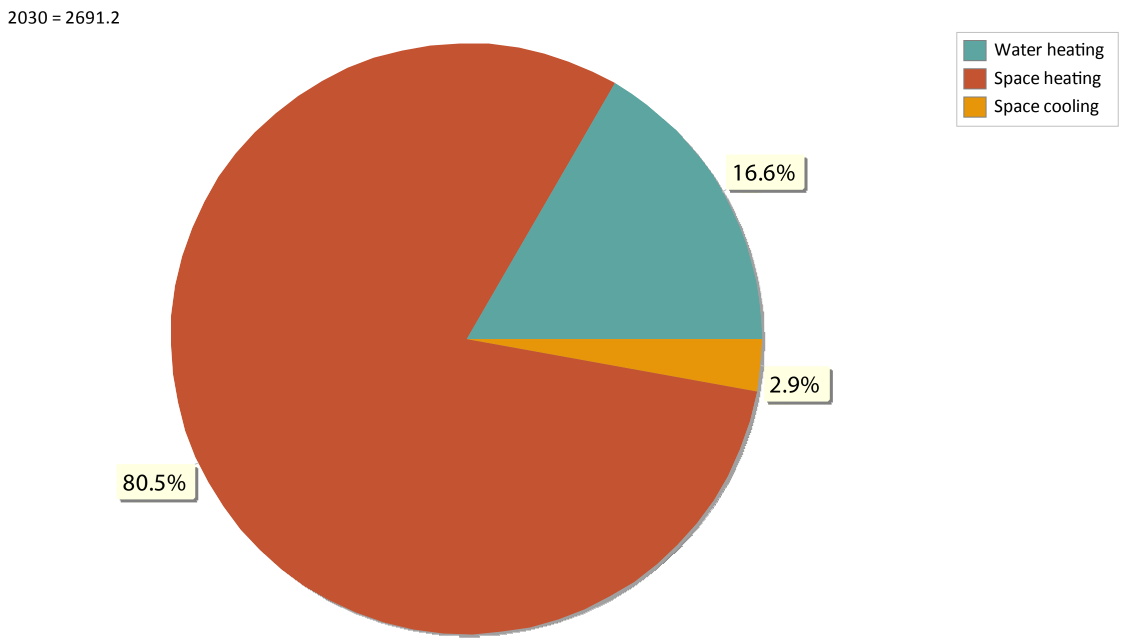


Figure 50 Structure of final energy consumption by end use in the reference scenario, 2030



consumers in our model will be EUR 0.112/kWh in 2020, and EUR 0.139/kWh in 2030.

Next, based on the report by our national consultants (see Section V, page 55) and comments made by Montenegrin experts, we assumed a current price of wood of EUR 0.04/kWh. Since electricity is the main substitute for wood in the residential sector, we assumed that the price of wood would increase according to the same trend as electricity.

Taking into account these assumptions, in 2030 energy costs to residential consumers in the business-as-usual scenario will reach EUR 207 million (Figure 52).

Figure 53 presents energy costs per square metre of the total building floor area. The figure shows that, in the business-as-usual scenario, residential consumers will pay around EUR 10/m^2 per year for thermal services in 2030.

Figure 51 **CO_2 emissions from electricity consumption in the reference scenario, 2015–2030**

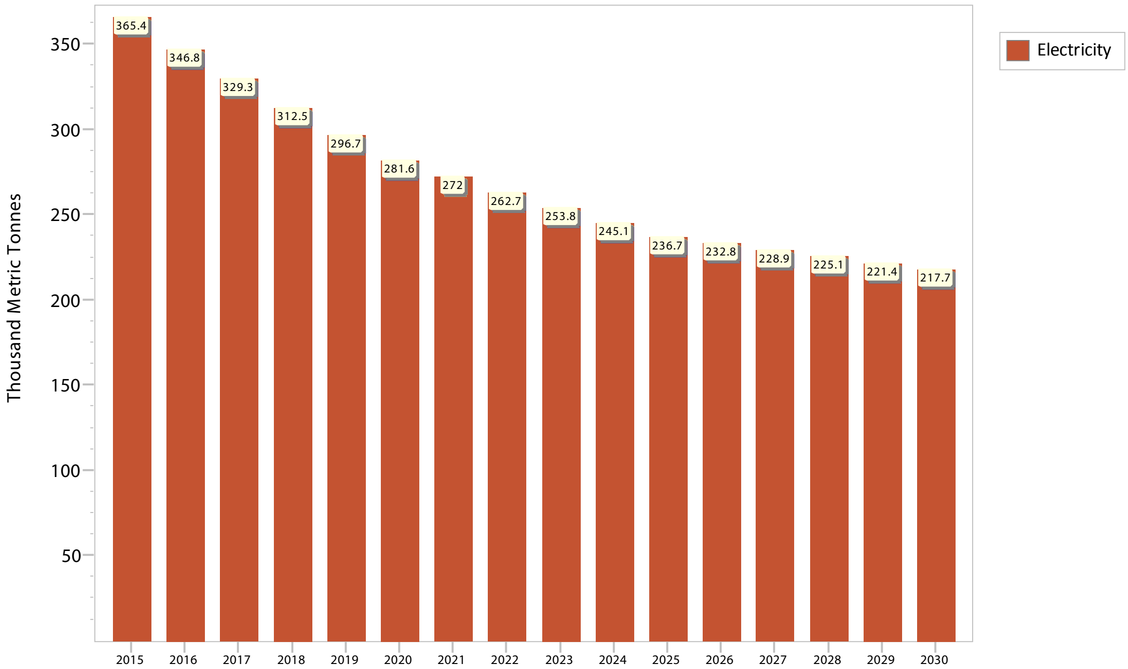


Figure 52 Energy costs in the reference scenario, 2015–2030

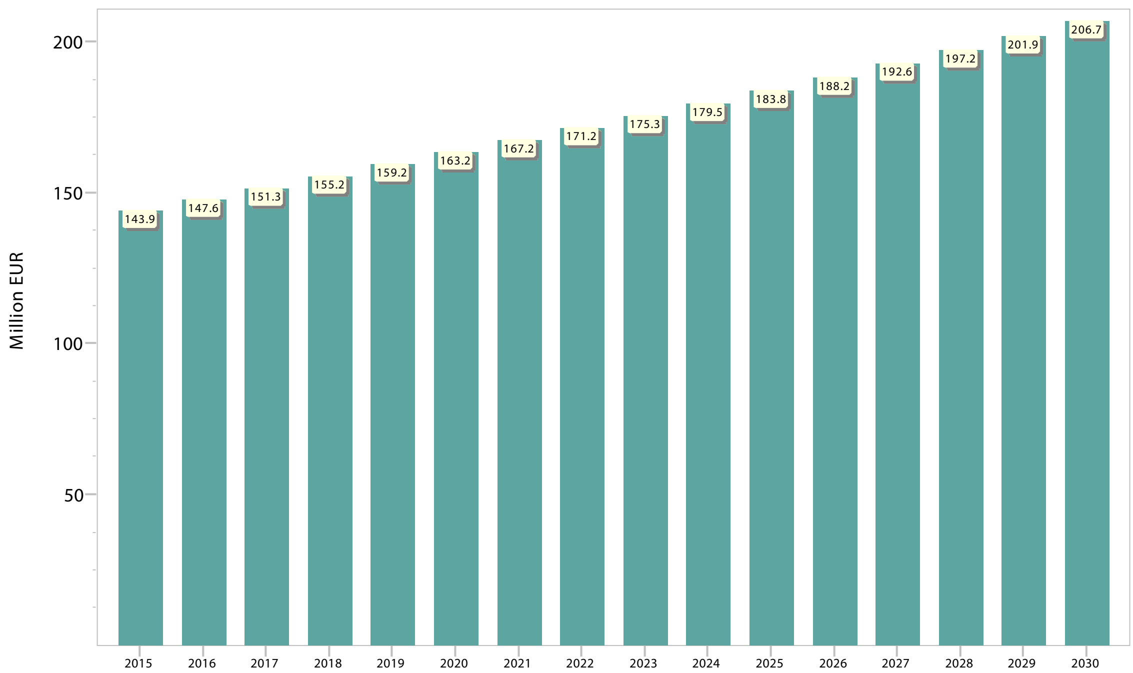
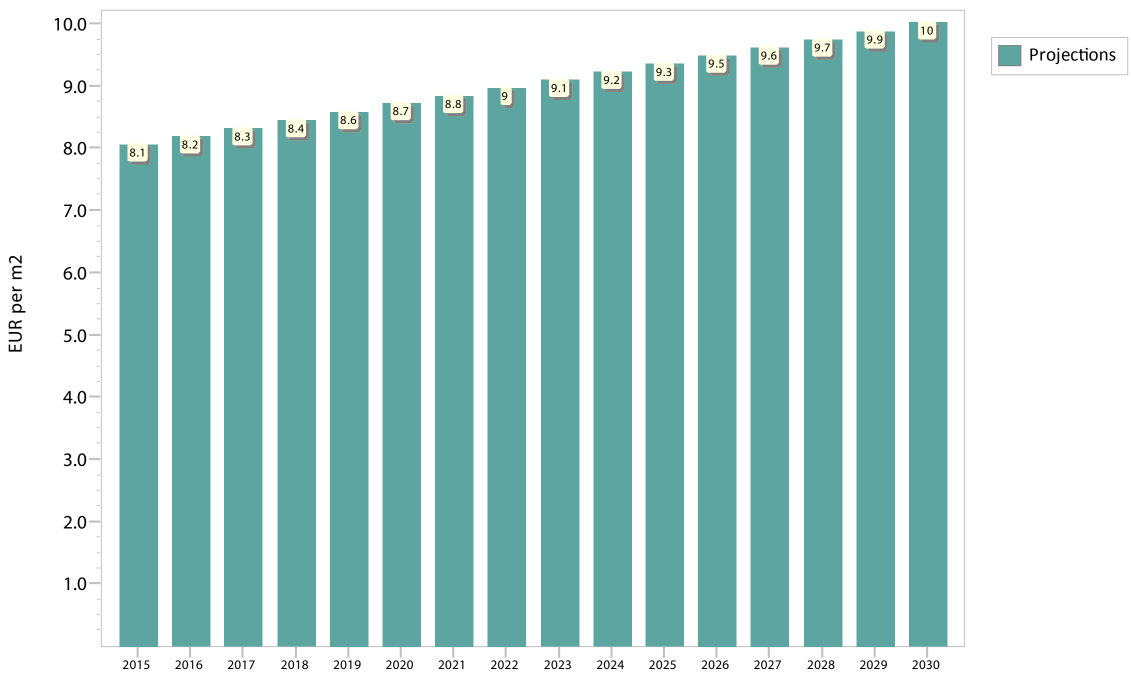


Figure 53 Annual energy costs per m² in the reference scenario, 2015–2030



XI. SLED moderate scenario: Results

Final energy consumption

In 2030, final energy consumption in the SLED moderate scenario, including renewable energy, will be around 2.3 billion kWh, or 15 percent lower than the business-as-usual level (Figure 54).

The net energy demand for thermal energy uses in the SLED moderate scenario will be addressed by electricity, wood and solar thermal energy in the future. The biggest final energy savings in absolute terms are associated with wood (Figure 55). Avoided wood consumption is around 285 million kWh, or 14 percent of the business-as-usual wood consumption in 2030. Avoided electricity consumption is about 131 million kWh, or 19 percent of the business-as-usual electricity consumption in 2030.

Figure 56 shows the share of final energy savings associated with the retrofitting of the thermal envelope of buildings constructed in 1971–1990. This category includes two decades, but even if split into two columns the final energy savings by decade would be greater than in any other decade.

Figure 57 shows the structure of final energy savings by building type. The majority of final energy savings originate from small buildings due to their dominant share in the total sector floor area as well as their high potential for energy savings per square metre. Retrofitting small buildings is a clear priority for policy making in Montenegro.

A breakdown of the reduction in net energy demand by building age and type shows that the key categories for net energy demand reduction are small buildings constructed in 1971–1990, 1991–2000, 2001–2015 and 1946–1970 (Figure 58).

Even though 26 percent of the building floor area is located in climate zone 3, 34 percent of the sector's final energy savings originate from this climate zone (Figure 59). Climate zone 1, which occupies around 50 percent of the sector's floor area, contributes around 49 percent of the sector's final energy savings.

Figure 60 shows final energy savings by building age and type, and climate zone. The biggest savings broken down to such a detailed level are located in small buildings constructed in 1971–1990 in climate zones

Figure 54 Final energy consumption in the SLED moderate scenario and final energy savings vs. the reference scenario, 2015–2030

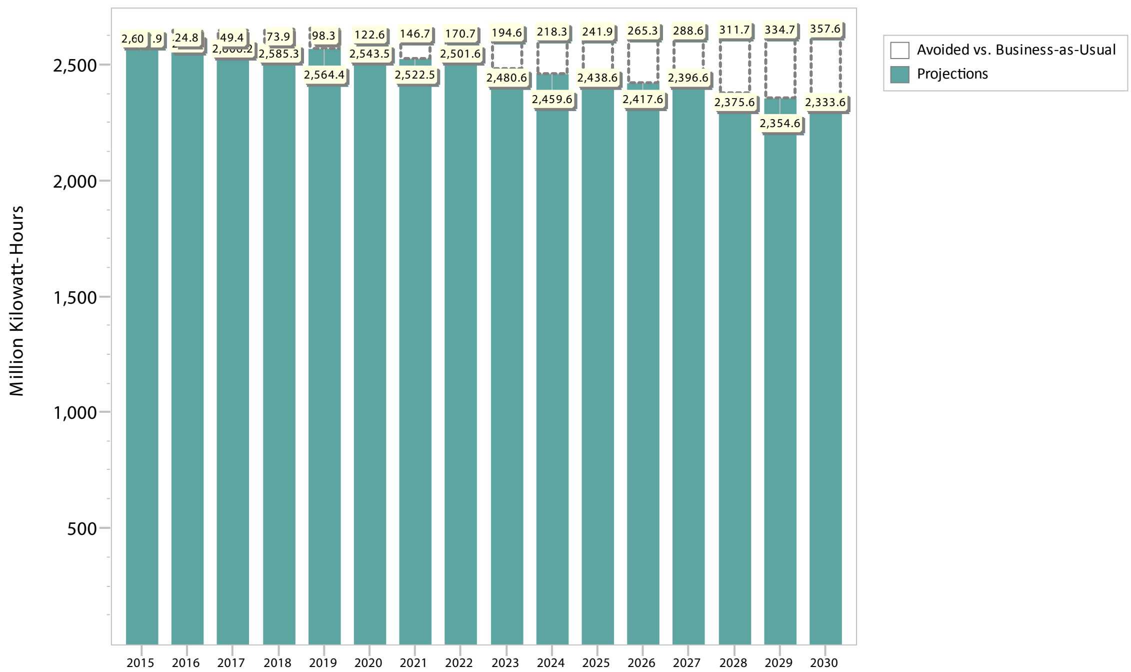


Figure 55 Final energy savings by energy source in the SLED moderate scenario vs. the reference scenario, 2015–2030

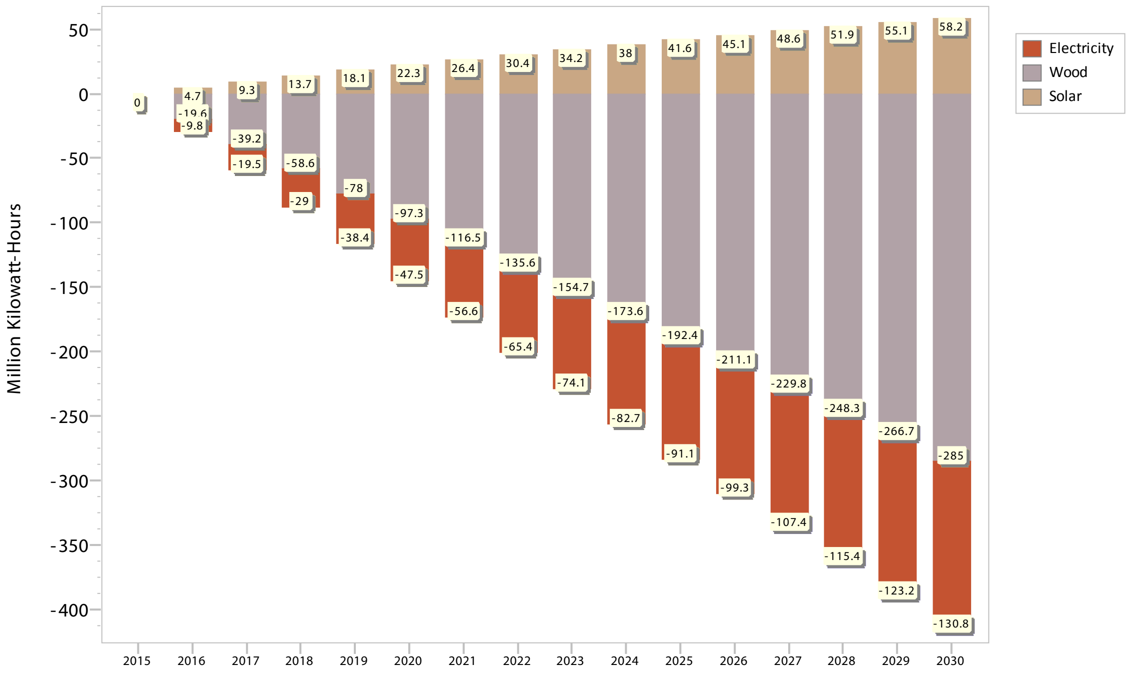


Figure 56 Final energy savings by building age category in the SLED moderate scenario vs. the reference scenario, 2015–2030

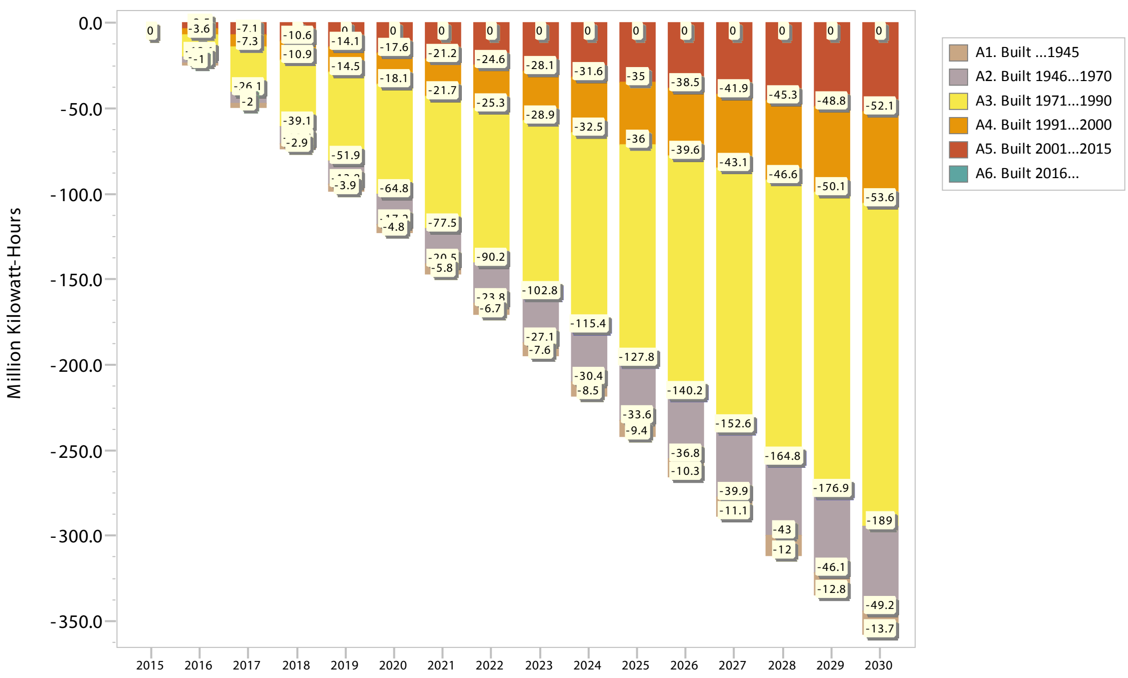


Figure 57 Final energy savings by building type in the SLED moderate scenario vs. the reference scenario, 2015–2030

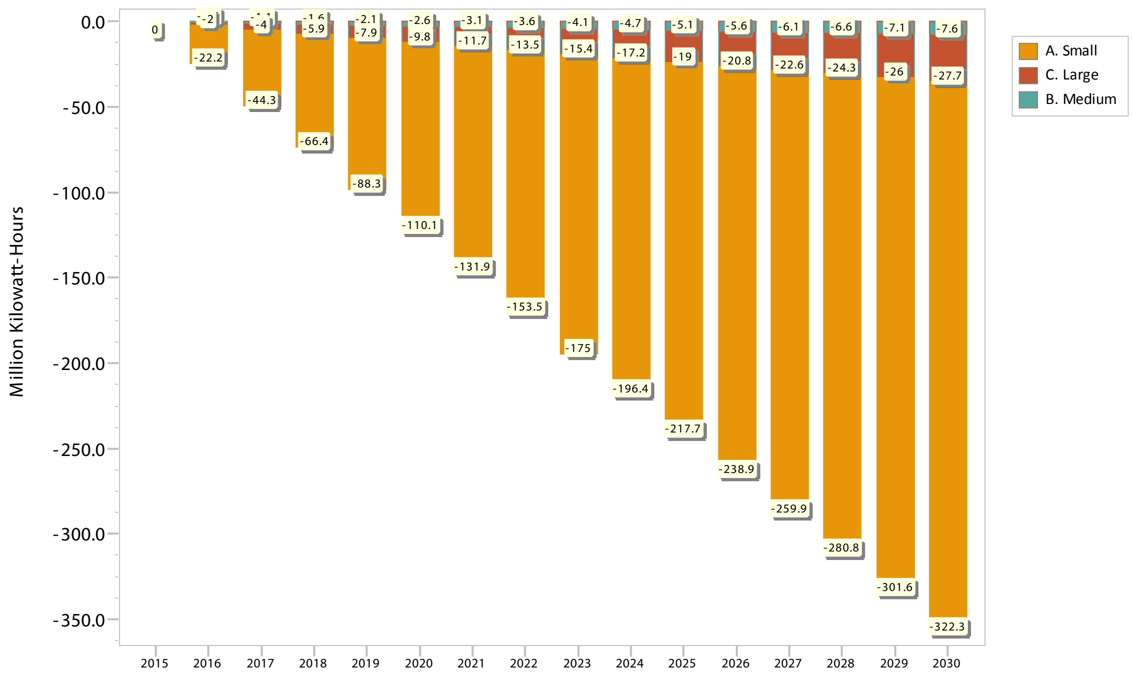
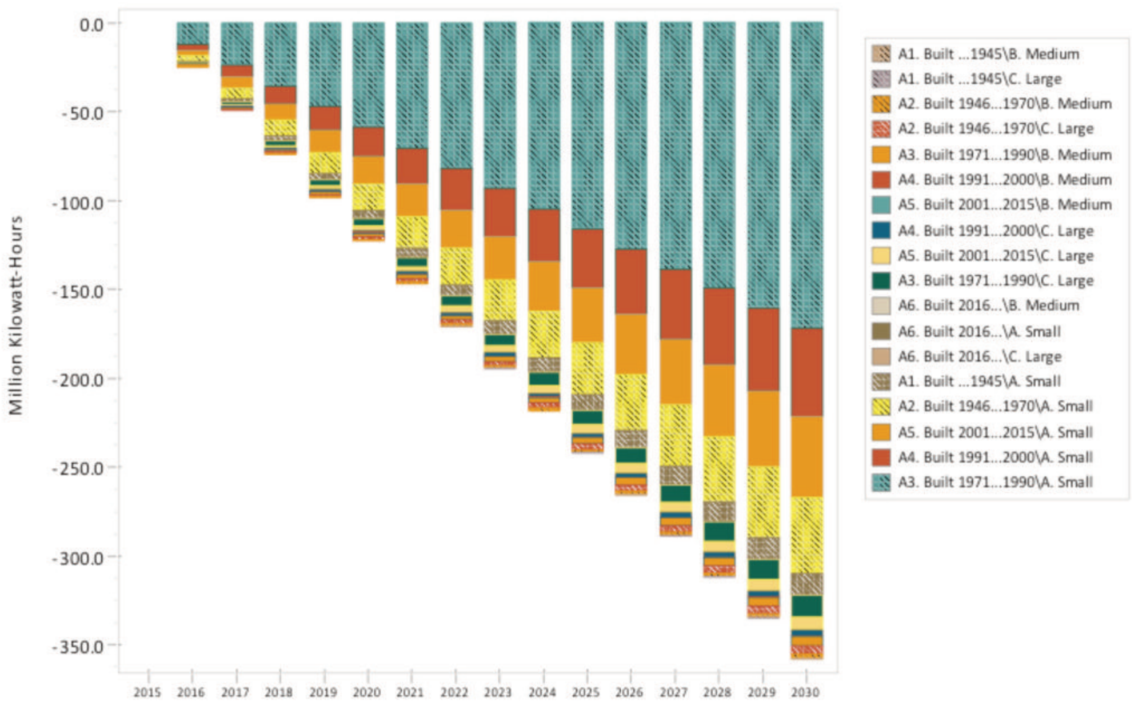


Figure 58 Final energy savings in the SLED moderate scenario by building age and type vs. the reference scenario, 2015–2030



1, 3 and 2 (23, 17 and 8 percent of total final energy savings respectively), followed by small buildings constructed in 1991–2000 in zones 1 and 3 (5 and 7 percent), small buildings constructed in 2001–2015 in zones 1 and 3 (6 and 5 percent), and small buildings constructed in 1946–1970 in zone 1 (6 percent).

As Figure 61 shows, the biggest final energy savings (91 percent of savings) are possible in space heating. Around 6 percent of energy savings are due to more efficient air-conditioning systems, and the remaining 3 percent to better water-heating technologies.

Average final energy consumption per square metre will be 15 percent lower in 2030 as compared to the business-as-usual level, and will reach 113 kWh/m^2 (Figure 62). The reduction in final energy consumption per square metre originates mostly from the retrofitting of existing buildings.

CO_2 emissions

The reduction in electricity consumption causes a reduction in the associated CO_2 emissions. As shown in Figure 63, emissions from the residential sector will be 23 percent lower in 2030 versus their business-as-usual level.

Saved energy costs

In 2030, energy costs for residential consumers in the SLED moderate scenario will be 20 percent lower than their energy costs in the business-as-usual case. In absolute terms, this difference amounts to EUR 34 million (Figure 64).

Figure 65 presents saved energy costs per square metre of the total building floor area. The figure shows that, in the SLED moderate scenario, residential consumers will pay around EUR 1.6/m^2 less for thermal services than in the business-as-usual case in 2030.

Figure 59 Final energy savings by climate zone in the SLED moderate scenario vs. the reference scenario, 2015–2030

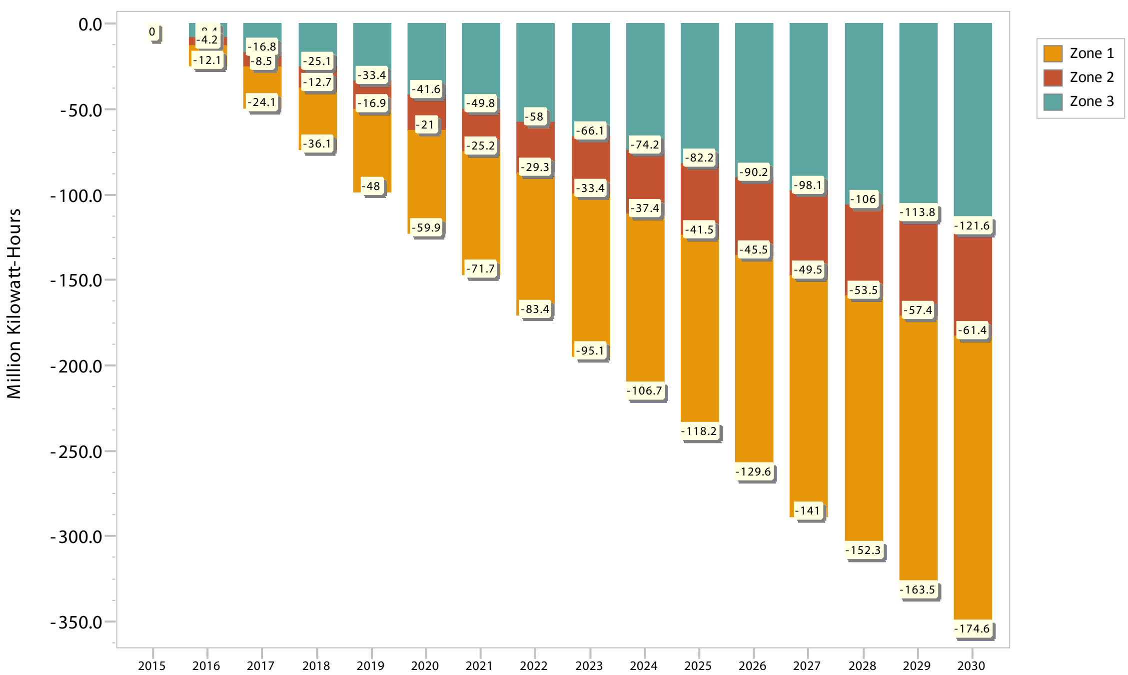


Figure 60 Final energy savings by building age and type and climate zone in the SLED moderate scenario vs. the reference scenario, 2015–2030

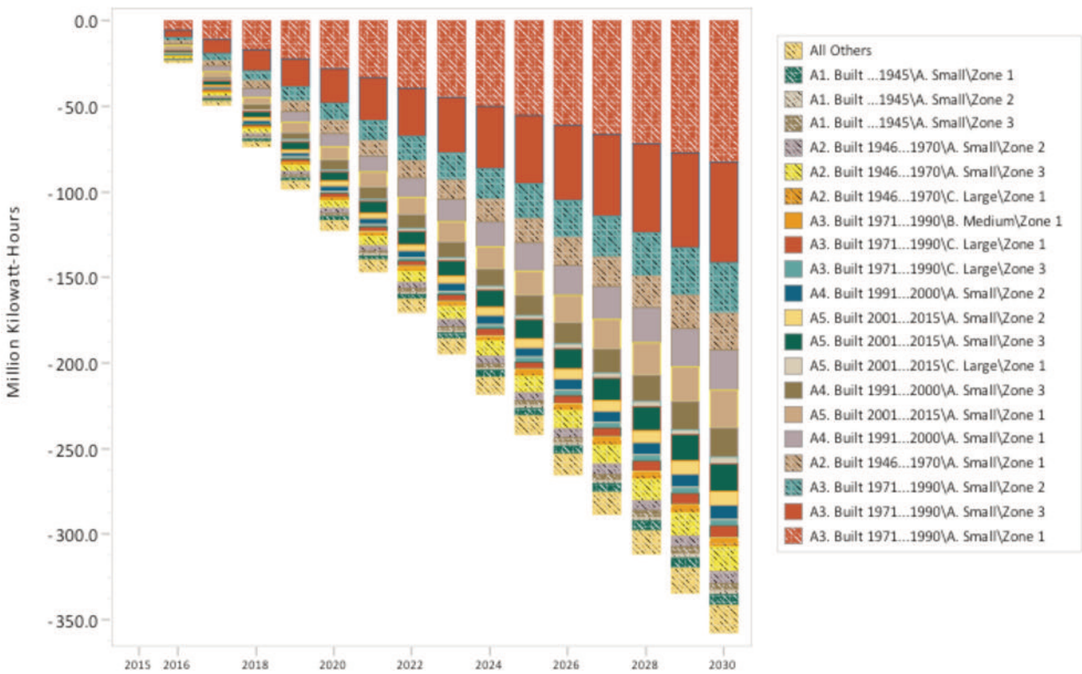


Figure 61 Final energy savings by end use in the SLED moderate scenario vs. the reference scenario, 2015–2030

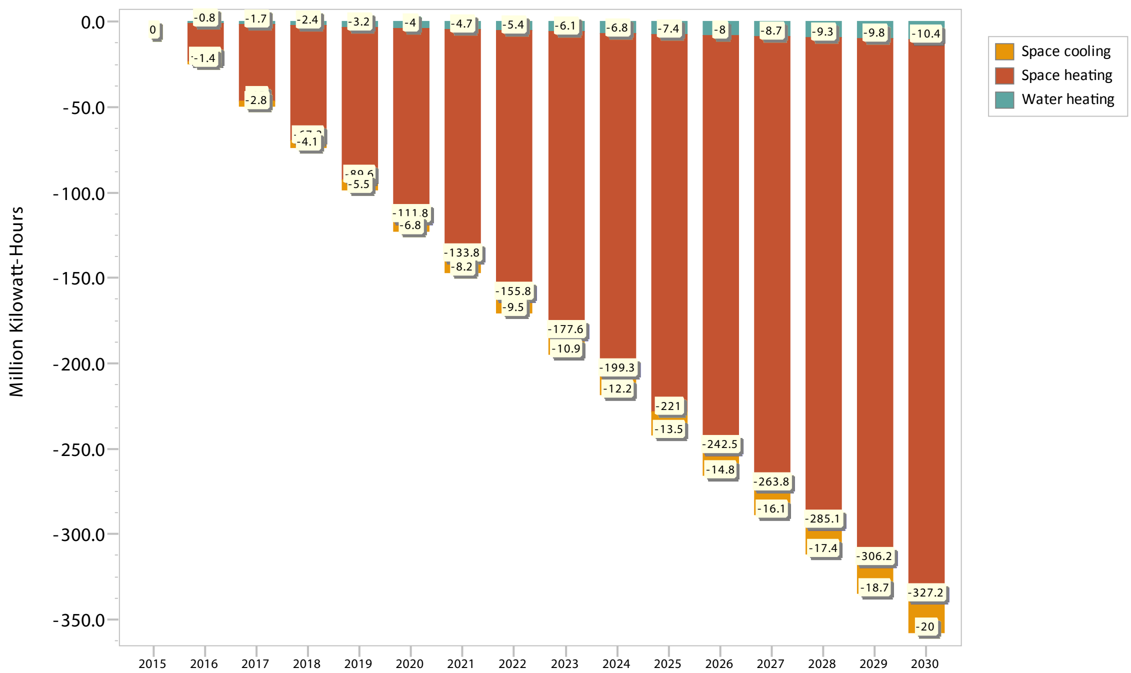


Figure 62 Final energy consumption per m² in the SLED moderate scenario and its reduction vs. the reference scenario, 2015–2030

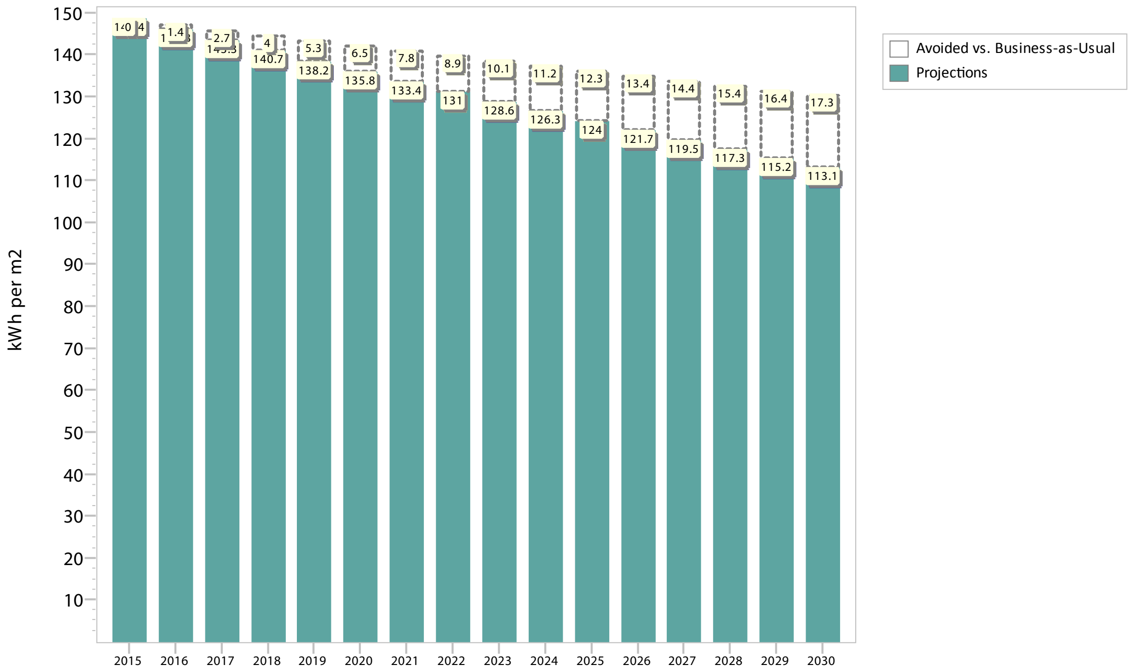
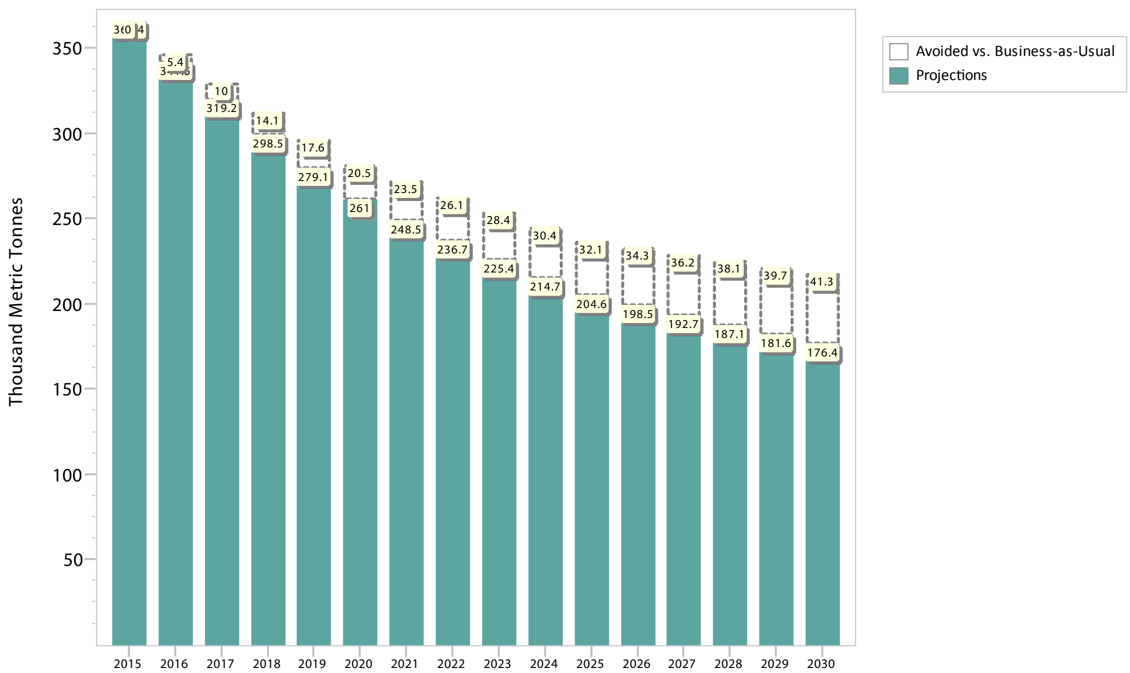


Figure 63 CO_2 emissions in the SLED moderate scenario and CO_2 emissions avoided vs. the reference scenario, 2015–2030



Investments

The transformation to a more efficient residential building stock in Montenegro requires significant investments. It is clear that they will not, and cannot, be financed from the public budget alone. The government aims to introduce policy tools and to use the available public budget to leverage private investments in thermally efficient retrofitting and construction.

Each building undergoes renovation at least once during its lifetime for different reasons, which are not necessarily linked to energy efficiency. The business-as-usual renovation costs often include plastering and painting, floor tiles, new windows and doors of mediocre quality, as well as the replacing of space-heating and water-heating systems. It is therefore both very convenient and more cost-effective to integrate thermal efficiency improvements to buildings in their business-as-usual retrofitting in order to take advantage of costs that are anyway incurred, and to pay in addition only the incremental costs of energy efficiency.

Below, we refer to the total investment costs of the scenarios as the total costs of the scenarios without deducting the business-as-usual costs that are incurred in the reference scenario. Under the incremental investment costs of the scenarios we understand the difference between the total costs of the scenarios and the business-as-usual costs of the reference scenario that are incurred anyway. As the retrofitting rates in the reference scenario and scenarios with additional measures may be different, the scenarios with additional measures may include not only the incremental costs but also the total investment costs for a part of the stock that is not affected by the business-as-usual renovations.

The retrofitting rate in the SLED moderate scenario is the same as the retrofitting rate in the reference scenario, which is why the incremental costs of the SLED moderate scenario include only the incremental costs of the thermal efficiency retrofitting of retrofitted buildings. In the case of newly constructed buildings, it makes sense to consider only the incremental costs of energy efficiency improvements, since the construction costs anyway include the business-as-usual costs of building components and systems.

In order to calculate the retrofitting costs at sector level, we multiplied the costs of building improve-

Figure 64 Energy costs in the SLED moderate scenario and saved energy costs vs. the reference scenario, 2015–2030

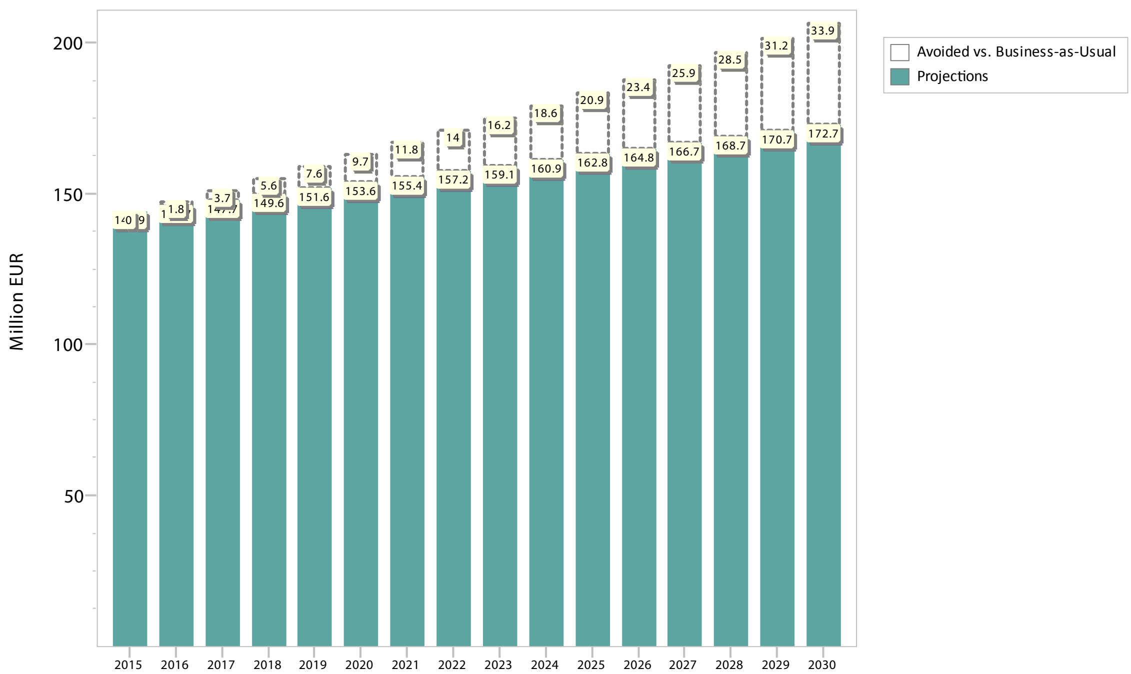
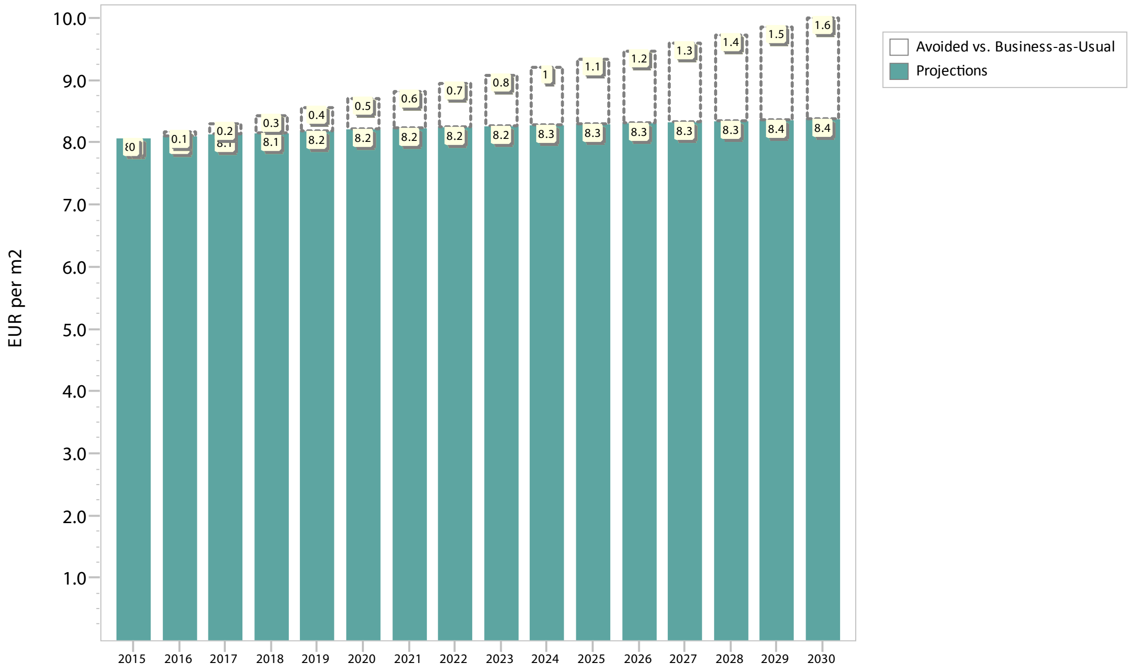


Figure 65 Energy costs per m² in the SLED moderate scenario and saved energy costs per m² vs. the reference scenario, 2015–2030



ments by the floor area affected by the SLED moderate scenario. The costs of building improvement 1 per square metre are documented in Section V. The costs of the business-as-usual improvements to existing buildings were assumed to be EUR 98/m² in the case of small buildings; EUR 59/m² for medium-sized buildings; and EUR 65/m² for large buildings.

Figure 66 shows the floor area affected by the SLED moderate scenario. On average, 314,000 m², or 1.6 percent of the total building floor area per year, are retrofitted between 2015 and 2030.

The retrofitting of the existing floor area is supported by low-interest loans and grants over the whole modelling period, as discussed in the assumptions in Section IX (page 80). The whole of the new building floor area is regulated by the building code.

In the case of existing buildings, we found that the average total investment cost per square metre was in the range of EUR 112 to 160, depending on the building type. If the business-as-usual costs are deducted from the total investment costs, the incremental costs of retrofitting the existing buildings are between EUR 53 and 71/m², depending on the building type.

Figure 67 presents the total costs of investments in the thermal efficiency retrofitting of buildings in the SLED moderate scenario over the modelling period. We estimated that, on average, these costs are around EUR 46 million per year between 2015 and 2030. The biggest investments are required for buildings constructed in 2001–2015 and 1971–1990. Over the modelling period, the cumulative total investment costs of the SLED moderate scenario are around EUR 692 million.

The model also makes it possible to break down the total investment costs according to the technological measures required. According to this analysis, the biggest share of the costs are for insulation and the replacement of water-heating systems (equal shares), followed by windows and the replacement of space-heating systems (equal shares), and finally the replacement of space-cooling systems.

Figure 66 Floor area of new and retrofitted buildings in the SLED moderate scenario, 2015–2030

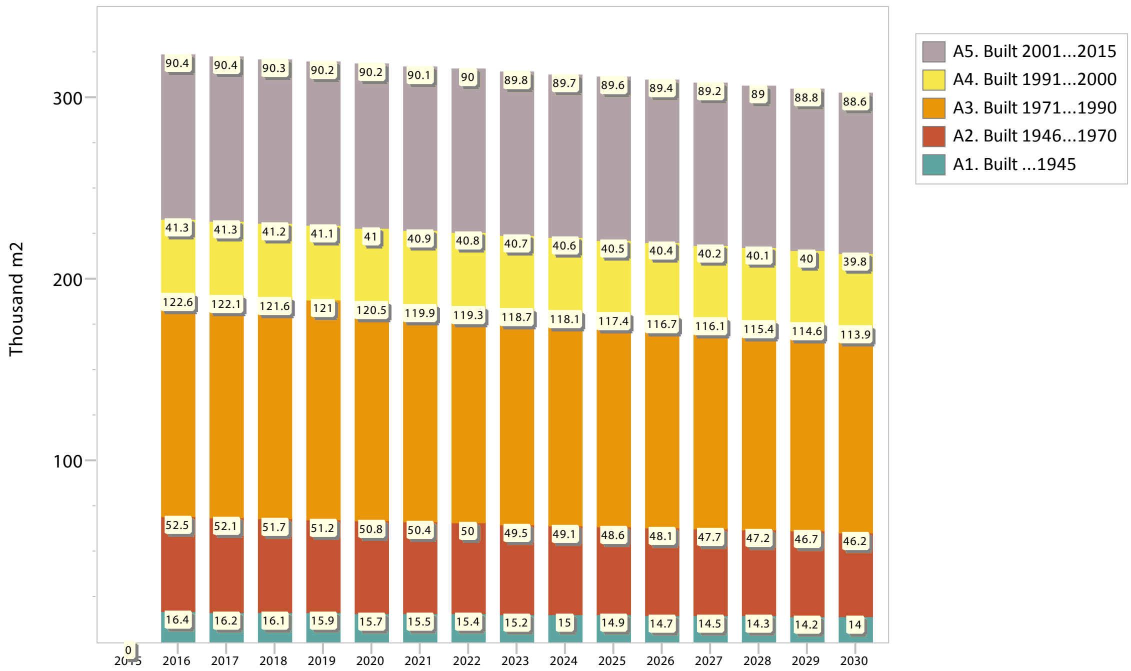
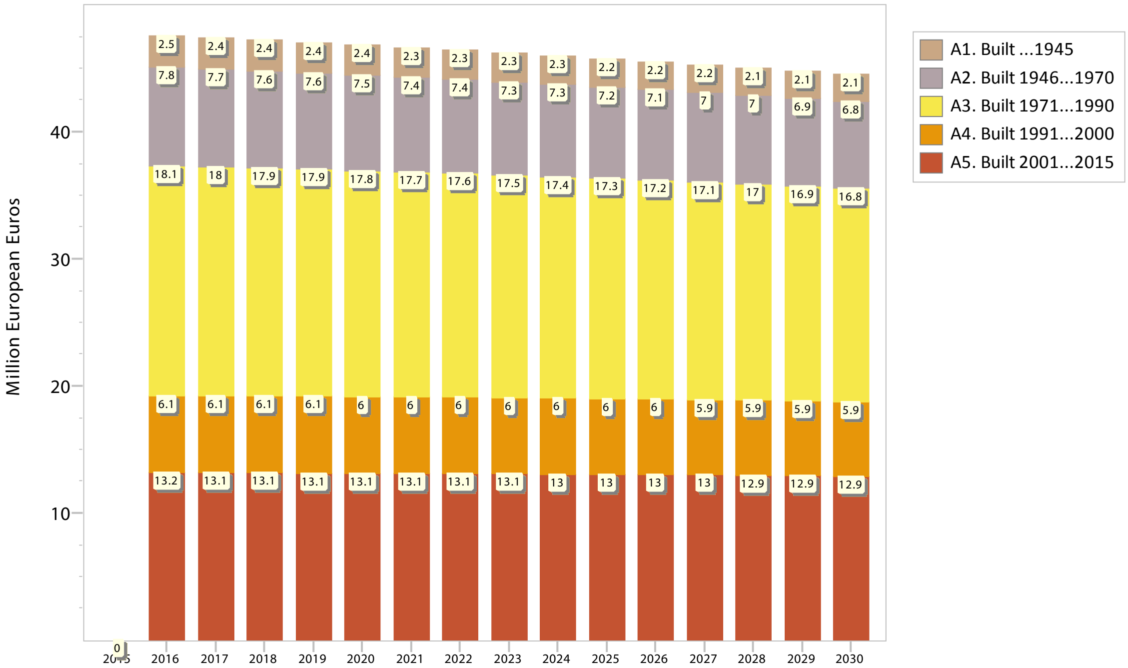


Figure 68 presents the incremental costs of investments in the thermal efficiency retrofitting of buildings and advanced construction in the SLED moderate scenario over the modelling period. The figure illustrates the clear benefit of coupling thermal efficiency improvements with the business-as-usual retrofitting of existing buildings. We estimated that the incremental investment costs of the scenario are on average EUR 19 million per year between 2015 and 2030. The cumulative incremental costs over the modelling period are around EUR 285 million.

Assuming a measure lifetime of 30 years and a discount rate of 4 percent, the annualised incremental cost of the SLED moderate scenario in 2015–2030 is EUR 1.9/m^2. The average saved energy costs are around EUR 3.6/m^2 of new or retrofitted floor area over the modelling period. This means that the investments in better existing and new buildings will pay back. It is important to note that the saved energy costs are greater than the annualised investment costs for the scenario as a whole at country level, but not for all building categories. For a few building categories, the saved energy costs are lower than the annualised incremental investment costs, thus in these cases the incremental investments do not pay back. Raising the discount rate higher than 10 percent would make the SLED moderate scenario unattractive if only saved energy costs are considered as scenario benefits. The analysis was carried out assuming a likely increase in energy prices.

We also analysed the efforts of different actors if Montenegro aims to follow the SLED moderate scenario. We conducted this analysis assuming a market loan interest rate of 10 percent, a government-subsidised loan interest rate of 0 percent, a loan term of 10 years, and a discount rate of 4 percent.

Figure 67 Total investment costs in the SLED moderate scenario, 2015–2030



In the model, we provided the option to assume eligible costs as a share of the total investment costs for each policy incentive in order to regulate the desired level of support. In our calculations we assumed that around 37 percent of the total investment costs would be supported with grants or low-interest loans for small buildings, and around 45 percent for medium-sized and large buildings. This is approximately equal to the share of incremental investment costs in the SLED moderate scenario.

According to the mechanism of low-interest loans, households borrow capital from commercial banks at a low interest rate and the government compensates the commercial banks for the difference between the market loan interest rate and the subsidised low-interest rate. Figure 69 shows the financing borrowed by residential stakeholders for the purposes of building retrofitting. Given our assumptions, the eligible costs of building retrofitting that would have to be borrowed by investors are around EUR 12 million per year, or around EUR 183 million over the modelling period.

Figure 70 shows the compensation paid by the government to commercial banks. Since the lending period is 10 years, the compensation paid by the government to commercial banks is at its highest in 10 years. After this, the amount of compensation stays almost the same until the end of the modelling period. Over the modelling period, the government provides EUR 84 million to commercial banks as compensation for the low interest rate.

The government also provides grants for the retrofitting of existing buildings, as described in the assumptions in Section IX (page 80). As Figure 71 shows, the value of these grants is around EUR 6.0 million per year, or EUR 89 million over the modelling period.

Figure 68 Incremental investment costs in the SLED moderate scenario, 2015–2030

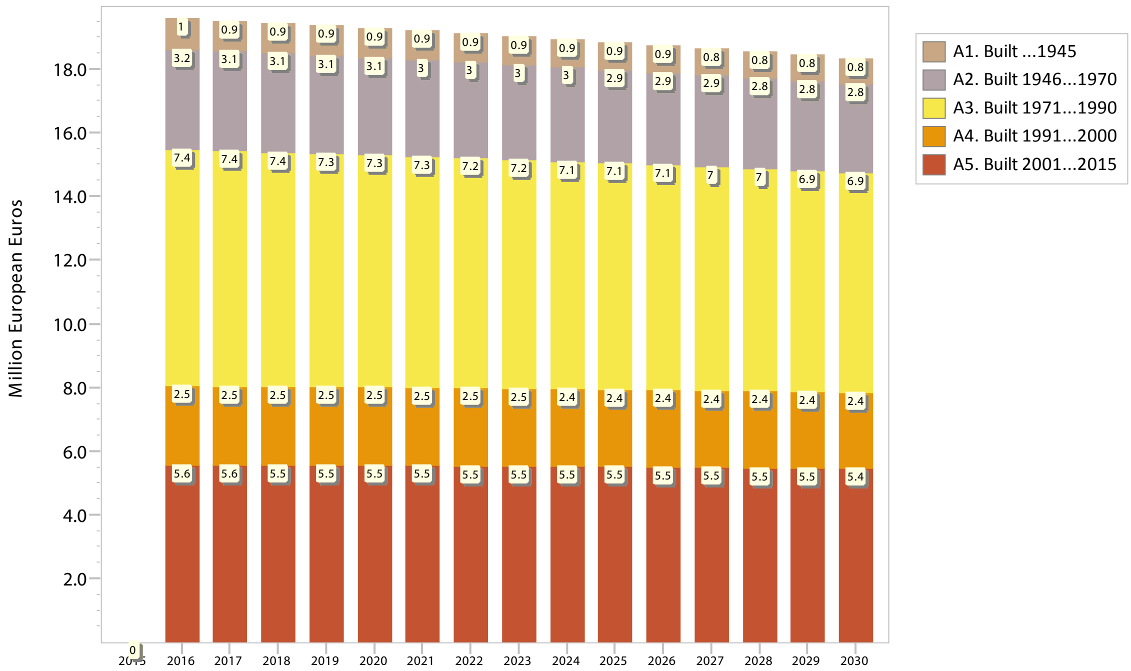


Figure 69 Private (eligible) investments stimulated by low-interest loans in the SLED moderate scenario, 2015–2030

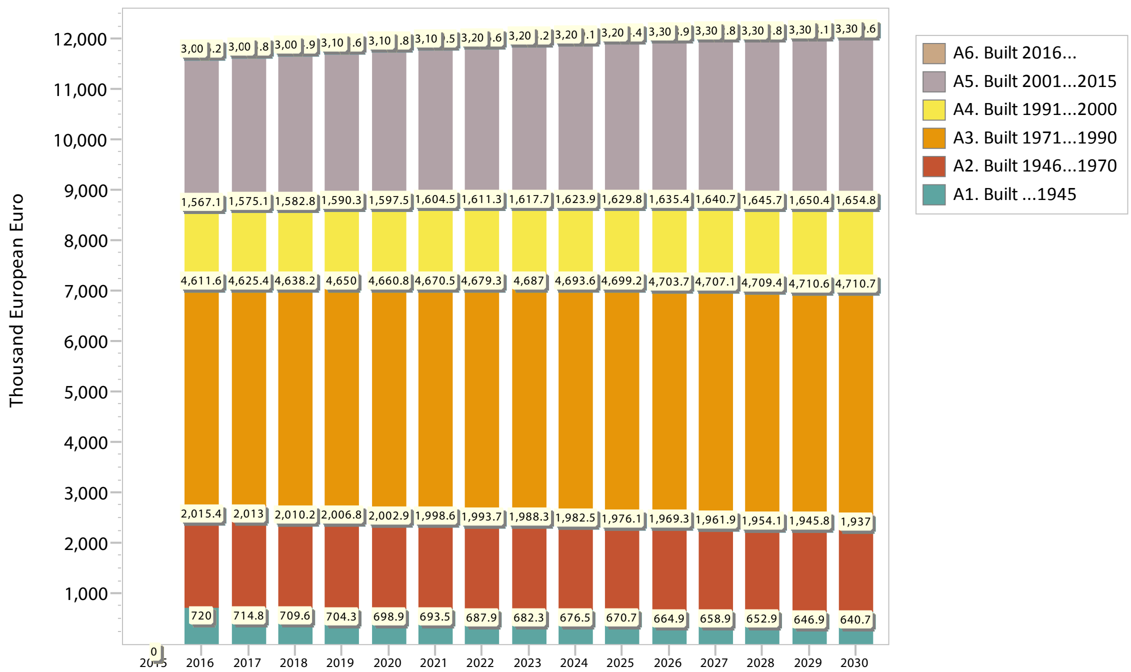


Figure 70 Cost to the government of low-interest loans in the SLED moderate scenario, 2015–2030

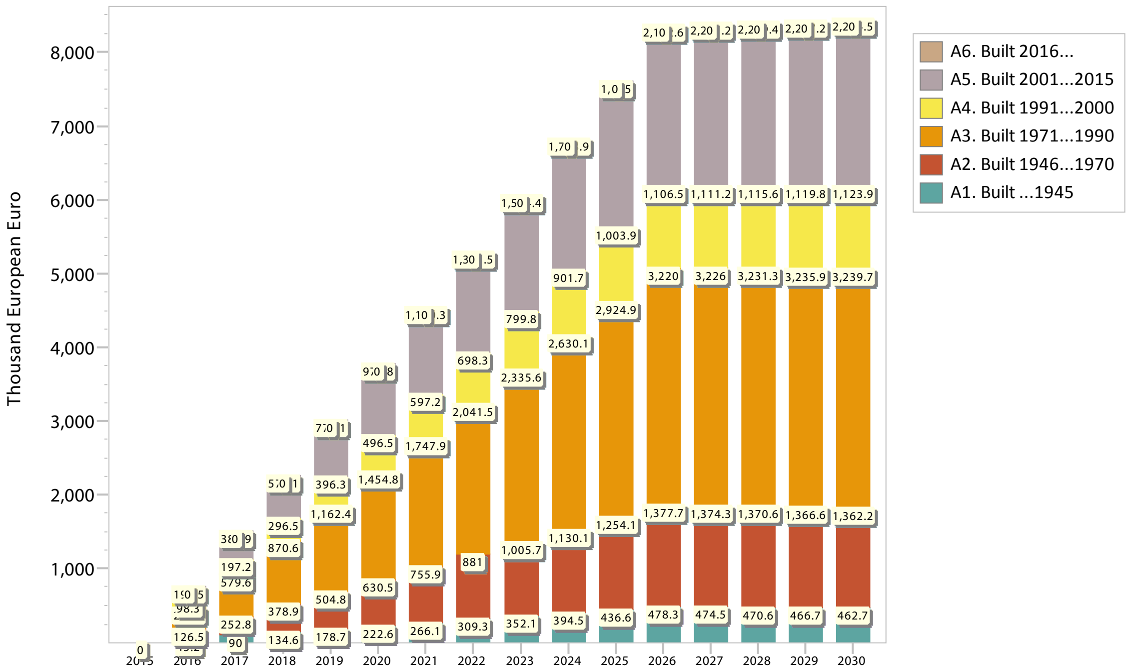
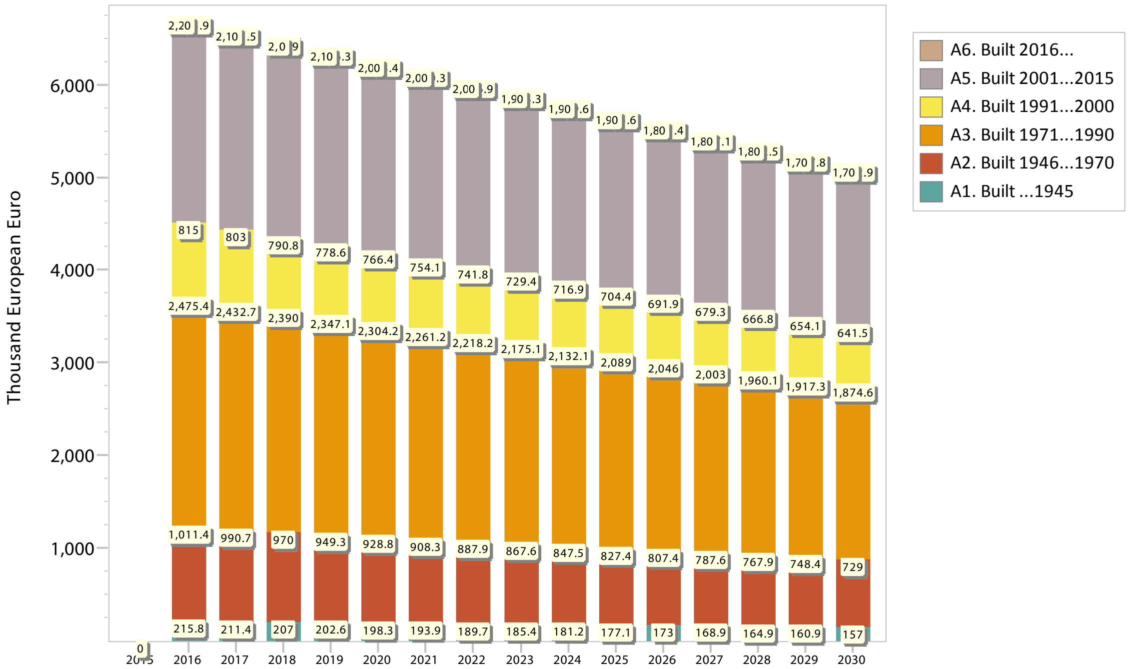


Figure 71 Cost to the government of grants in the SLED moderate scenario, 2015–2030



XII. SLED ambitious scenario: Results

Final energy consumption

In 2030, final energy consumption in the SLED ambitious scenario will be approximately 2.1 billion kWh, or 23 percent lower than the business-as-usual level (Figure 72).

The biggest final energy savings are associated with wood (Figure 73). Avoided wood consumption is around 315 million kWh, or 23 percent of the business-as-usual wood consumption in 2030. Avoided electricity consumption is about 455 million kWh, or 46 percent of the business-as-usual electricity consumption in 2030.

Figure 74 shows that, similar to the SLED moderate scenario, the majority of final energy savings are associated with the retrofitting of the thermal envelope of buildings constructed in 1971–1990. The category covers two decades, but even if split into two columns the final energy savings by decade would be higher than in any other decade. Other age categories that are significant in terms of final energy savings are buildings constructed in 2001–2015 and buildings constructed after 2016.

Figure 75 shows the structure of final energy savings by building type. The figure shows that the majority of the final energy savings originate from small buildings, due to their dominant share in the sector's floor area, as well as their greater potential for energy savings. The retrofitting of small buildings is a clear priority for policy making in Montenegro.

The breakdown of final energy savings by building age and type shows that the key categories are small buildings constructed in 1971–1990, 1991–2000, 2001–2015, 1946–1970, and after 2016 (Figure 76).

Even though 26 percent of the building floor area is located in climate zone 3, this climate zone is responsible for 40 percent of the sector's final energy savings (Figure 77). Climate zone 1, which occupies around 50 percent of the sector's floor area, is responsible for around 44 percent of the sector's final energy savings.

Figure 78 shows final energy savings by building age and type and climate zone. The figure shows that the biggest savings, broken down to such a detailed level, originate from small buildings constructed in 1971–1990 in zones 3 and 1 (17 percent and 18 percent of

Figure 72 Final energy consumption in the SLED ambitious scenario and final energy savings vs. the reference scenario, 2015–2030

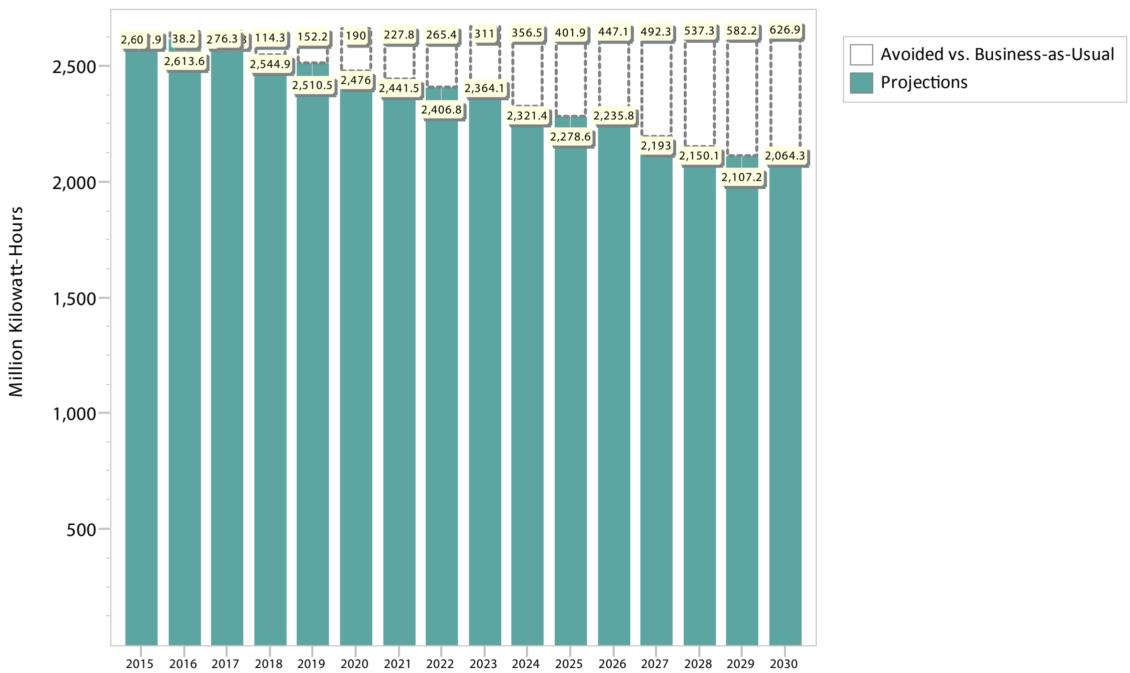


Figure 73 Final energy savings by energy source in the SLED ambitious scenario vs. the reference scenario, 2015–2030

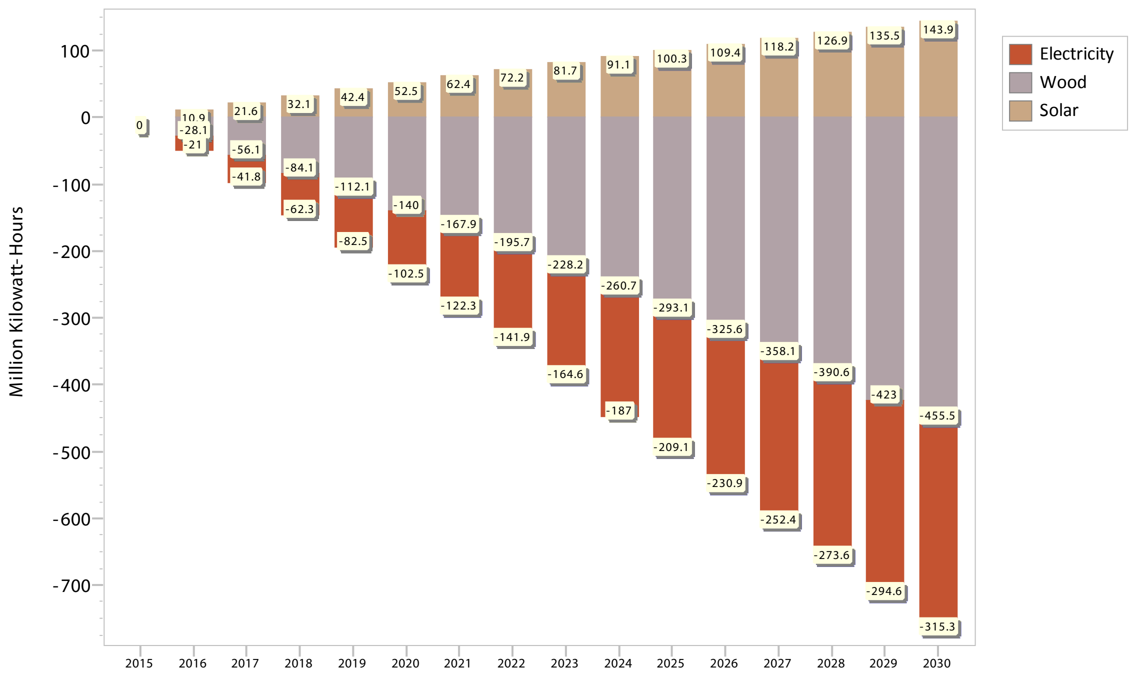


Figure 74 Final energy savings in the SLED ambitious scenario vs. the reference scenario by building age category, 2015–2030

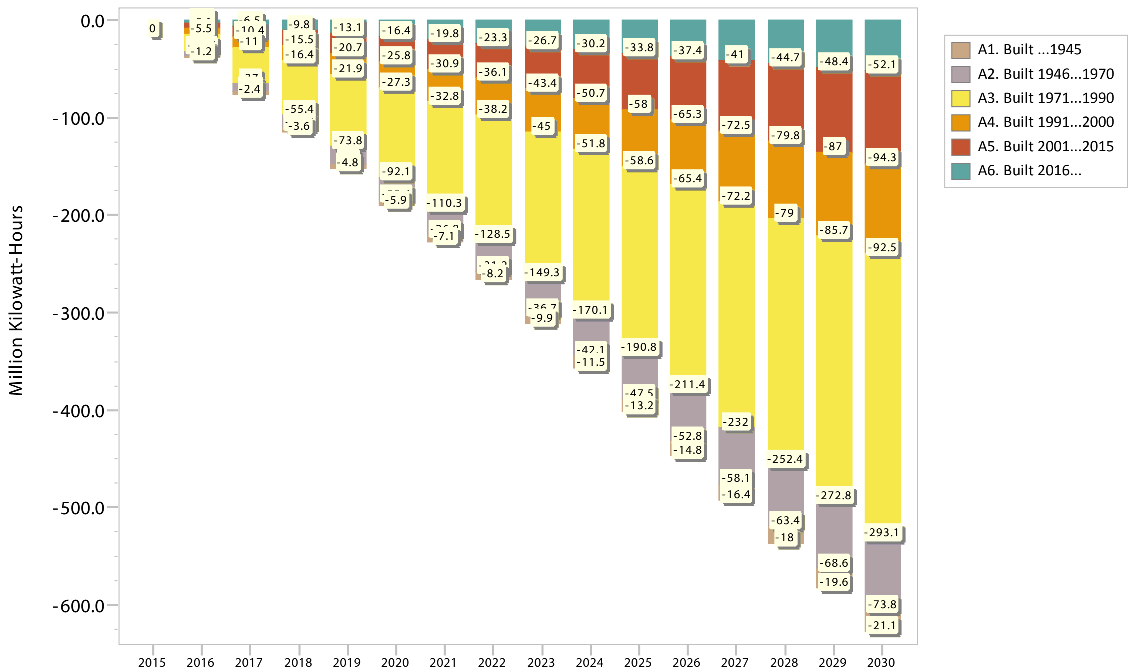


Figure 75 Final energy savings by building type in the SLED ambitious scenario vs. the reference scenario, 2015–2030

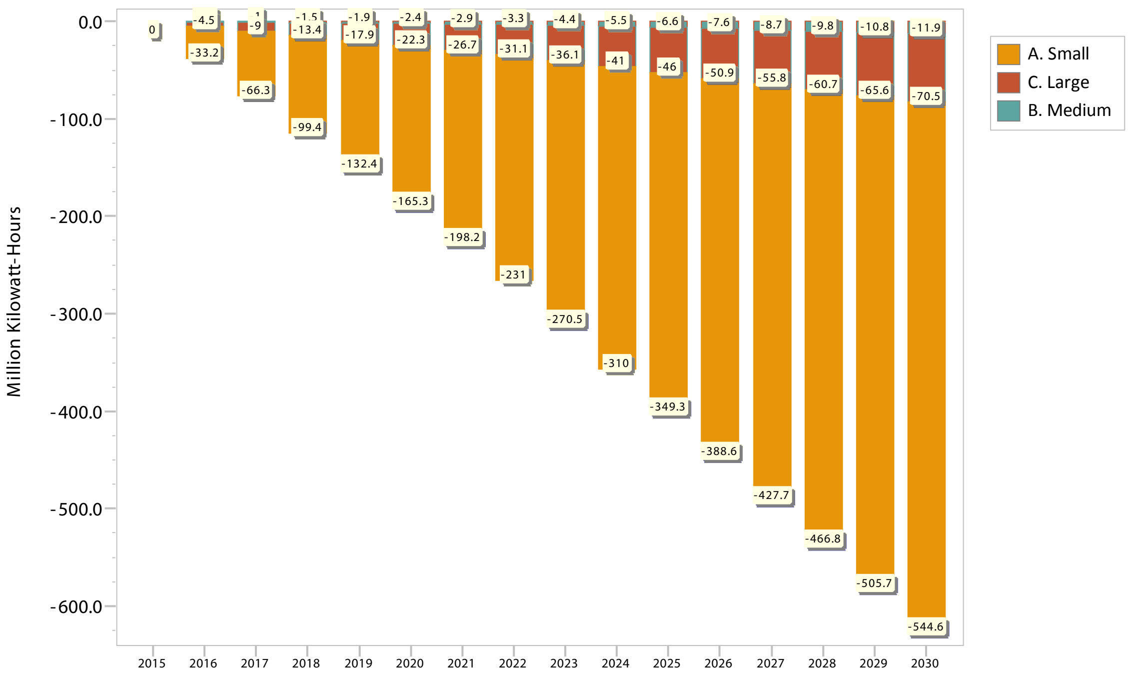
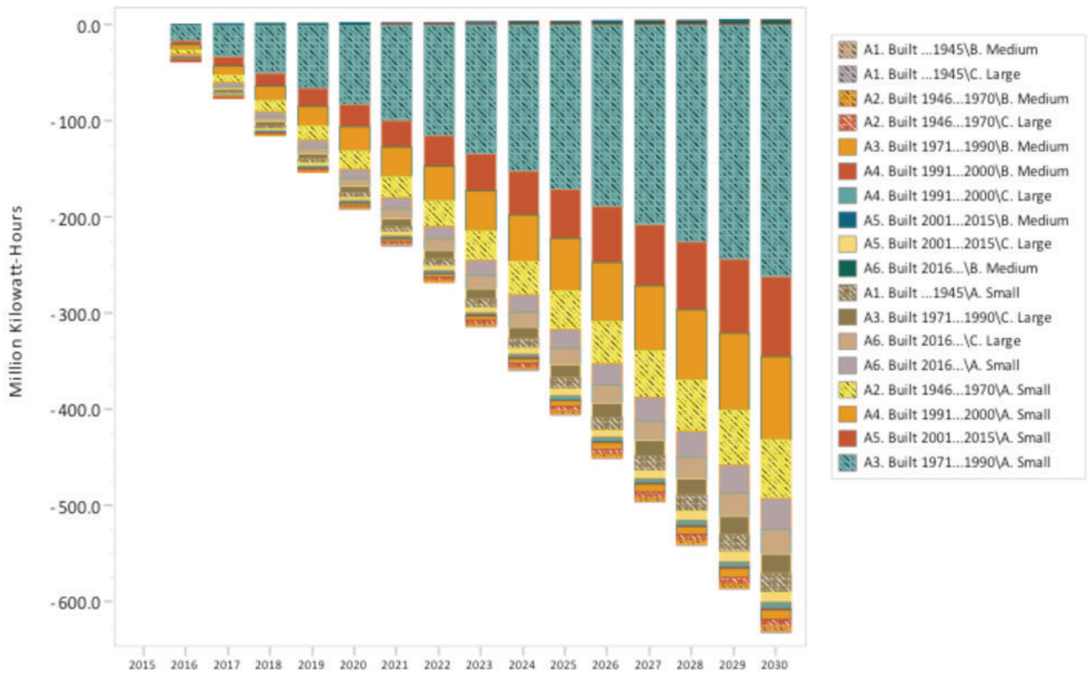


Figure 76 Final energy savings in the SLED ambitious scenario vs. the reference scenario by building age and type, 2015–2030



the total final energy savings respectively), then in small buildings built in 1991–2000 in zones 3 and 1 (6 percent each), and small buildings built in 2001–2015 in zones 3 and 1 (6 percent each).

As Figure 79 shows, the biggest final energy savings are possible in space heating (93 percent of savings). Around 4 percent of energy savings are due to more efficient air-conditioning systems, and the remaining 3 percent due to better water-heating technologies.

Average final energy consumption per square metre will be 23 percent lower in 2030 as compared to the business-as-usual level, reaching around 100 kWh/m^2 (Figure 80). The reduction in final energy demand per square metre originates mostly from the retrofitting of existing buildings.

CO_2 emissions

The reduction in electricity consumption causes a reduction in the associated CO_2 emissions. As Figure 81 illustrates, emissions from the residential sector will be 46 percent lower in 2030 versus their business-as-usual level.

Saved energy costs

In 2030, energy costs to residential consumers in the SLED ambitious scenario will be 33 percent lower than the energy costs in the business-as-usual case in 2030. In absolute terms, this difference represents EUR 69 million (Figure 82).

Figure 83 shows saved energy costs per square metre of the total building floor area. The figure illustrates that, in the SLED ambitious scenario, in 2030 residential consumers will pay around EUR 3.3/m^2 per year less for thermal services than in the business-as-usual case.

Investments

Section XI (page 98) defines the total and incremental investment costs of the SLED scenarios, thus the information is not repeated here. Section XI also elaborates on the importance and cost-effectiveness of integrating thermal efficiency improvements to buildings into their business-as-usual renovation. The retrofitting rate in the SLED ambitious scenario is higher than the retrofitting rate of the reference

Figure 77 Final energy savings by climate zone in the SLED ambitious scenario vs. the reference scenario, 2015–2030

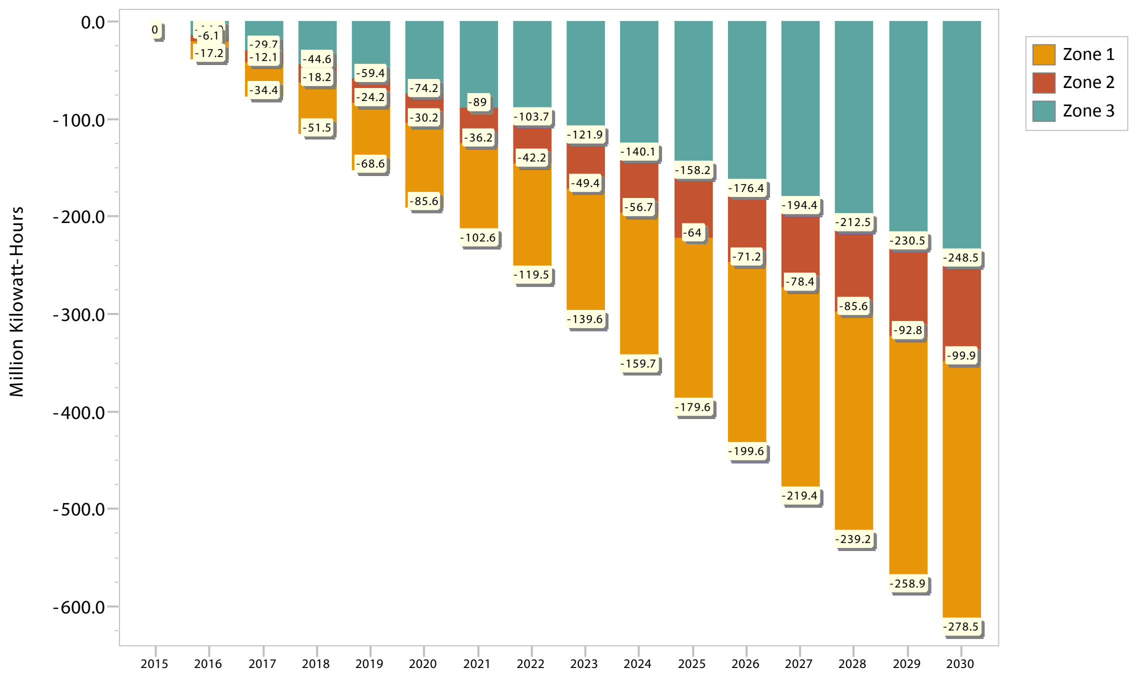


Figure 78 Final energy savings by building age and type and climate zone in the SLED ambitious scenario vs. the reference scenario, 2015–2030

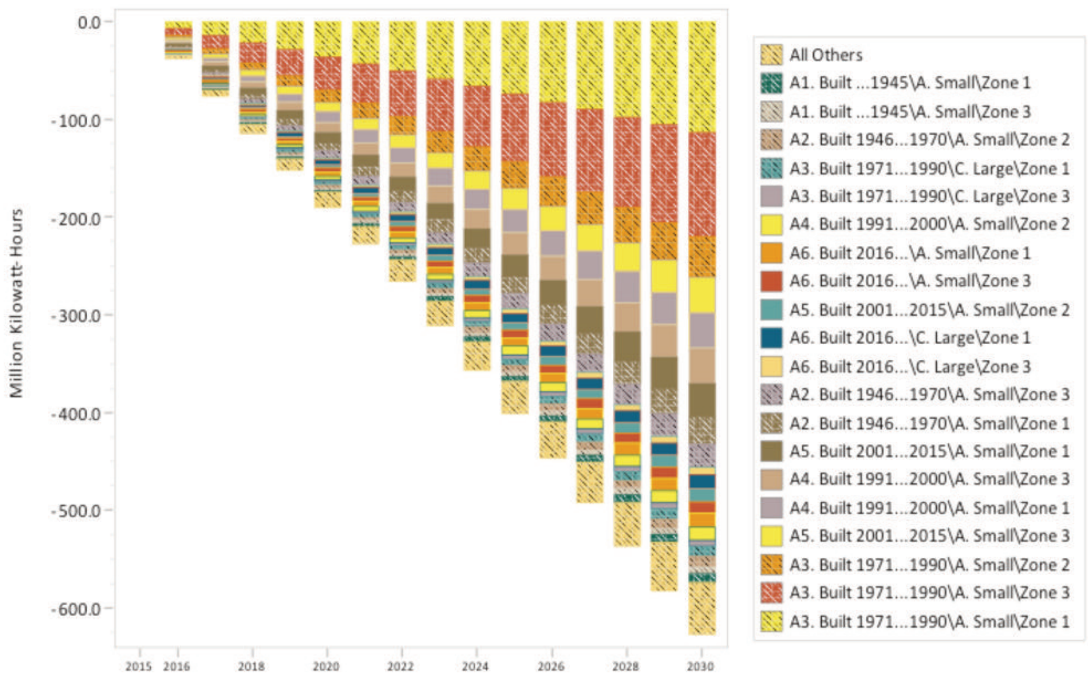


Figure 79 Final energy savings by end use in the SLED ambitious scenario vs. the reference scenario, 2015–2030

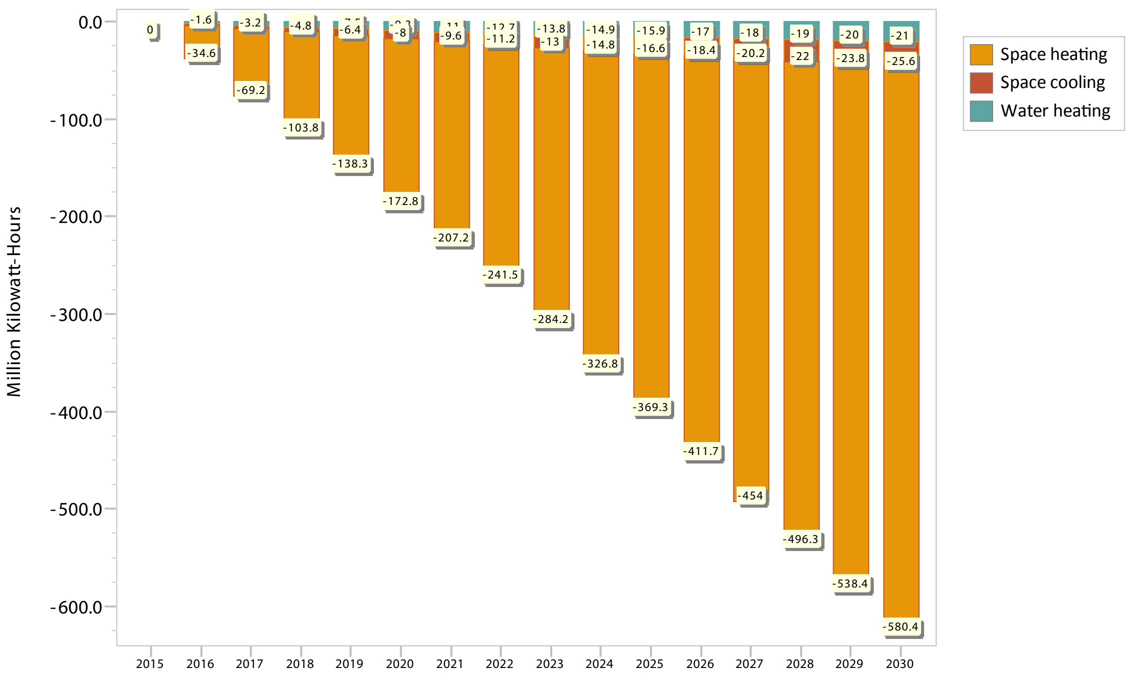


Figure 80 Final energy consumption per m² in the SLED ambitious scenario and its reduction vs. the reference scenario, 2015–2030

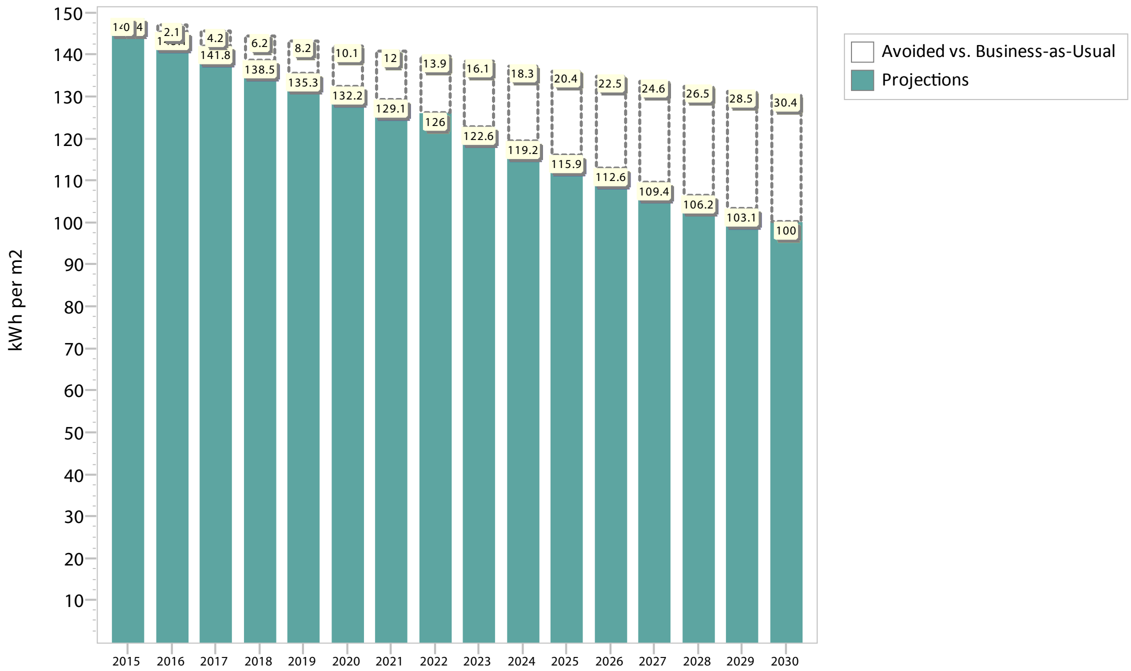


Figure 81 CO_2 emissions in the SLED ambitious scenario and CO_2 emissions avoided vs. the reference scenario, 2015–2030

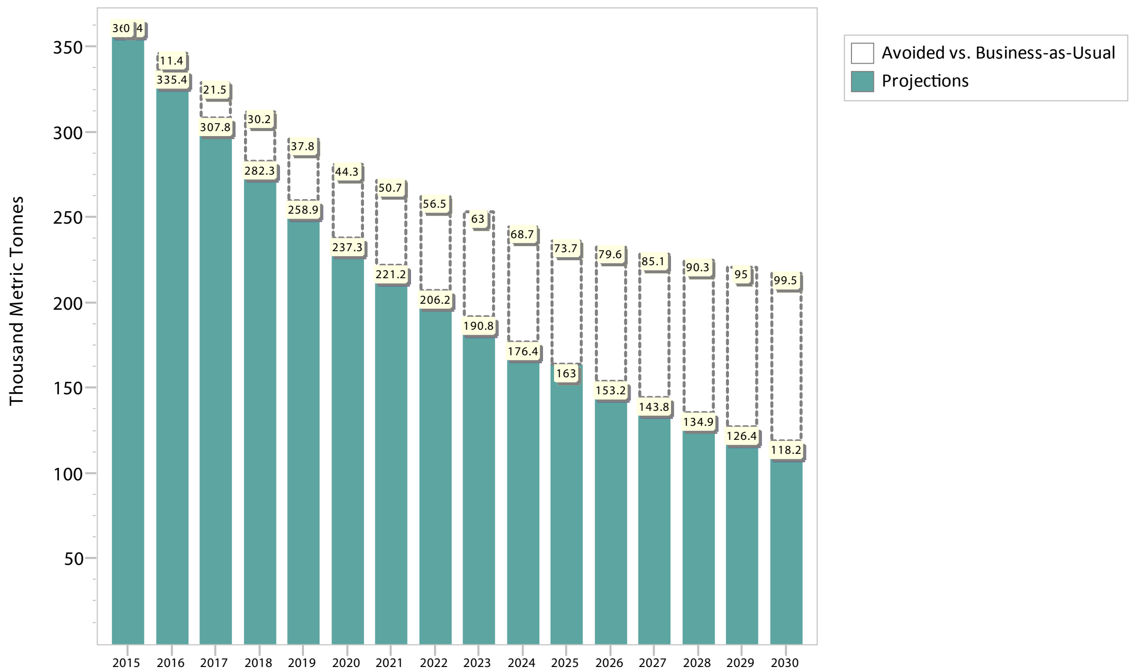


Figure 82 Energy costs in the SLED ambitious scenario and saved energy costs vs. the reference scenario, 2015–2030

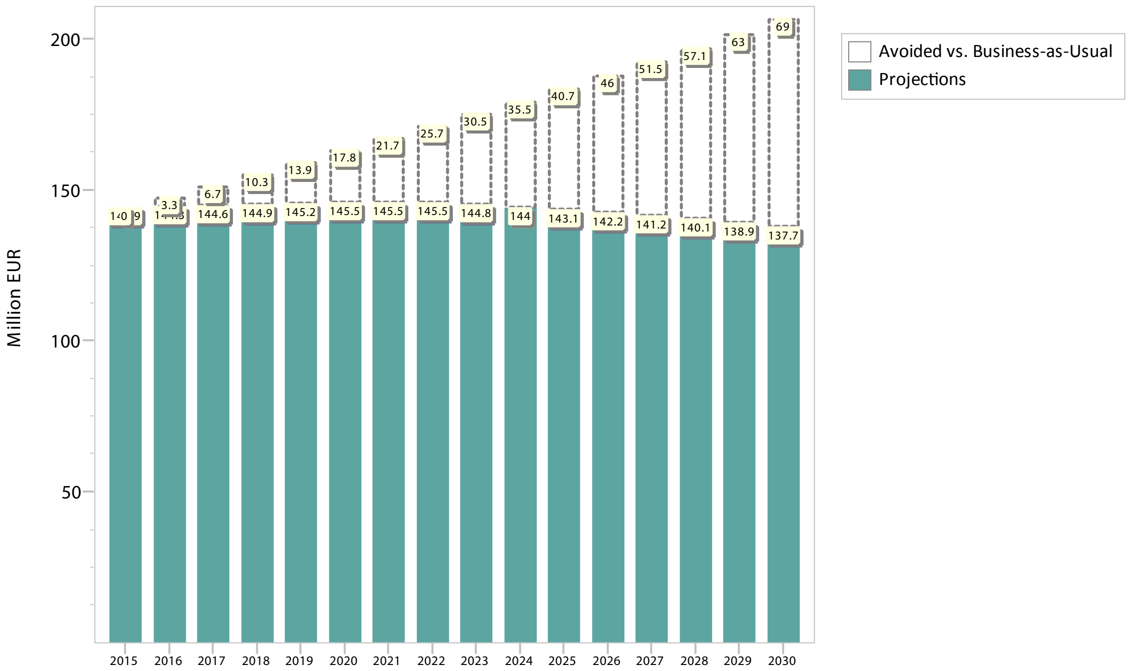
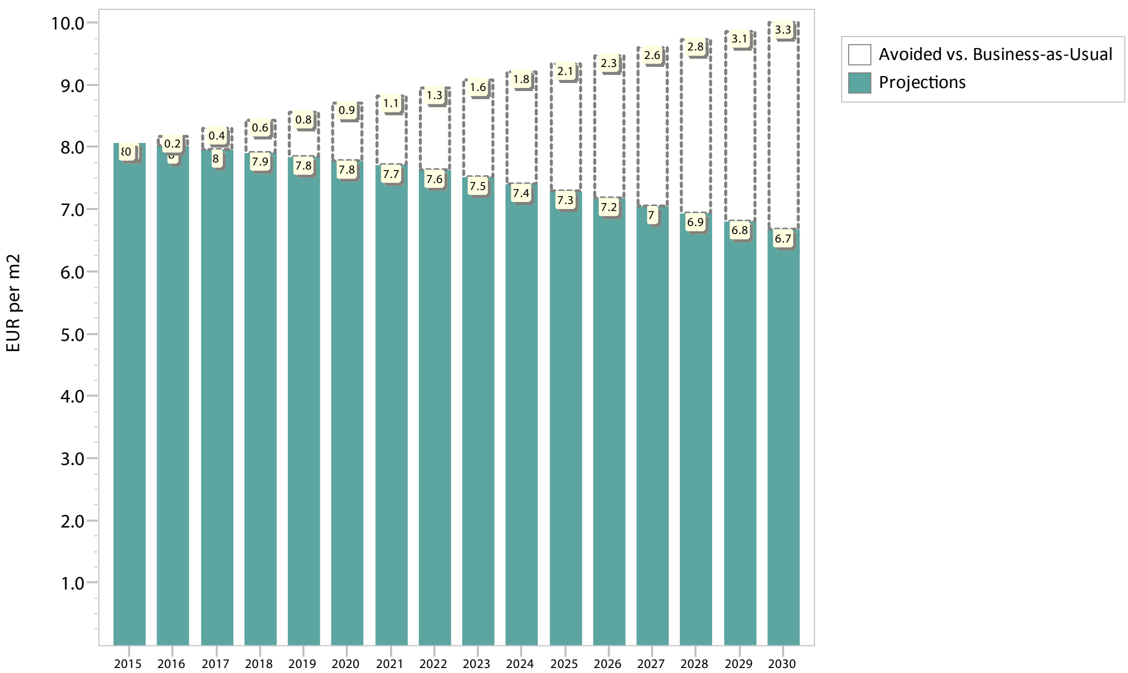


Figure 83 Energy costs per m² in the SLED ambitious scenario and saved energy costs per m² vs. the reference scenario, 2015–2030



scenario, which is why the incremental costs of the SLED ambitious scenario include the incremental investment costs of thermal efficiency retrofitting for part of the retrofitted building stock and the total investment costs of the thermal efficiency retrofitting of the rest of the retrofitted building stock.

Similar to the SLED moderate scenario, in order to calculate retrofitting costs at sector level we multiplied the costs of building improvements by the floor area affected by the SLED ambitious scenario. The costs of building improvement 2 per square metre are documented in Section V. The costs of the business-as-usual improvement of existing buildings are the same as in the SLED moderate scenario.

Figure 84 shows the floor area affected by the SLED ambitious scenario. On average, 425,000 m^2, or 2.4 percent of the total building floor area per year, are retrofitted between 2015 and 2030. In addition, all new floor area — that is, around 250,000 m^2 per year — is included in our scenario.

The retrofitting of the existing floor area is supported by low-interest loans and grants over the whole modelling period, as discussed in the assumptions in Section IX. The whole of the new building floor area is supported up until 2022 by low-interest loans in order to reach a level of performance according to improvement 2. Starting from 2023, the whole of the new building floor area is regulated by the building code, corresponding to improvement 2, as discussed in the assumptions in Section IX (page 80).

For new buildings, we estimated that the average incremental investment in greater energy efficiency is EUR 43 to EUR 57/m^2, depending on the building type. For existing buildings, we found the average total investment cost to be in the range of EUR 112 to EUR 157/m^2, depending on the building age, between 2015 and 2022; and in the range of EUR 155 to EUR 214/m^2 between 2023 and 2030. If the business-as-usual costs are deducted from the total investment costs, the incremental costs of retrofitting existing buildings are around EUR 53 to EUR 72/m^2, depending on the building age, between 2015 and 2022; and in the range of EUR 96 to EUR 129/m^2 between 2023 and 2030.

Figure 85 presents the total investment costs of the SLED ambitious scenario in the thermal efficiency retrofitting of buildings over the modelling period. We estimated that, on average, the total retrofitting costs are approximately EUR 80 million per year between 2015 and 2030. The biggest investments are required for buildings constructed in 2001–2015. Over the modelling period, the cumulative total investment costs in the SLED ambitious scenario are around EUR 1.2 billion.

It is also possible in the model to break down the total investment costs into the technological measures required. According to this analysis, the biggest share of costs are for insulation, followed by the replacement of space-heating systems, the replacement of water-heating systems, new windows, and finally the replacement of space-cooling systems.

Figure 86 presents the incremental investment costs in the SLED ambitious scenario in the thermal efficiency retrofitting of buildings and advanced construction over the modelling period. The figure illustrates the clear benefit of coupling thermal efficiency improvements with the business-as-usual retrofitting of existing buildings. We estimated that the incremental investment costs of building retrofitting are on average EUR 53 million per year between 2015 and 2030. The cumulative incremental costs of building retrofitting in the SLED ambitious scenario over the modelling period are around EUR 796 million. In addition, the incremental investment costs of new, more efficient buildings are on average around EUR 15 million per year, or EUR 230 million over the modelling period.

Assuming a measure lifetime of 30 years and a discount rate of 4 percent, the annualised incremental cost of the SLED ambitious scenario over 2015–2030 is EUR 5.4/m^2. The average saved energy costs are around EUR 5.5/m^2 of new or retrofitted floor area over the modelling period. This means that the investments in the SLED ambitious scenario will pay back, but raising the discount rate higher would make them unattractive if only saved energy costs are considered as scenario benefits. Similar to the SLED moderate scenario, the saved energy costs are higher than the annualised investment costs in the SLED ambitious scenario as a whole at country level, but not for all building categories.

We also analysed the efforts of different actors if Montenegro aims to follow the SLED ambitious scenario. All assumptions in the financial analysis in the SLED ambitious scenario are the same as the respective assumptions in the SLED moderate scenario. In the SLED ambitious scenario, we assumed that around 54 percent of the total investment costs of retrofitting would be supported by grants or low-interest loans for small buildings, and around 57 percent in the case of medium-sized and large buildings. Also, around

Figure 84 Floor area of new and retrofitted buildings in the SLED ambitious scenario, 2015–2030

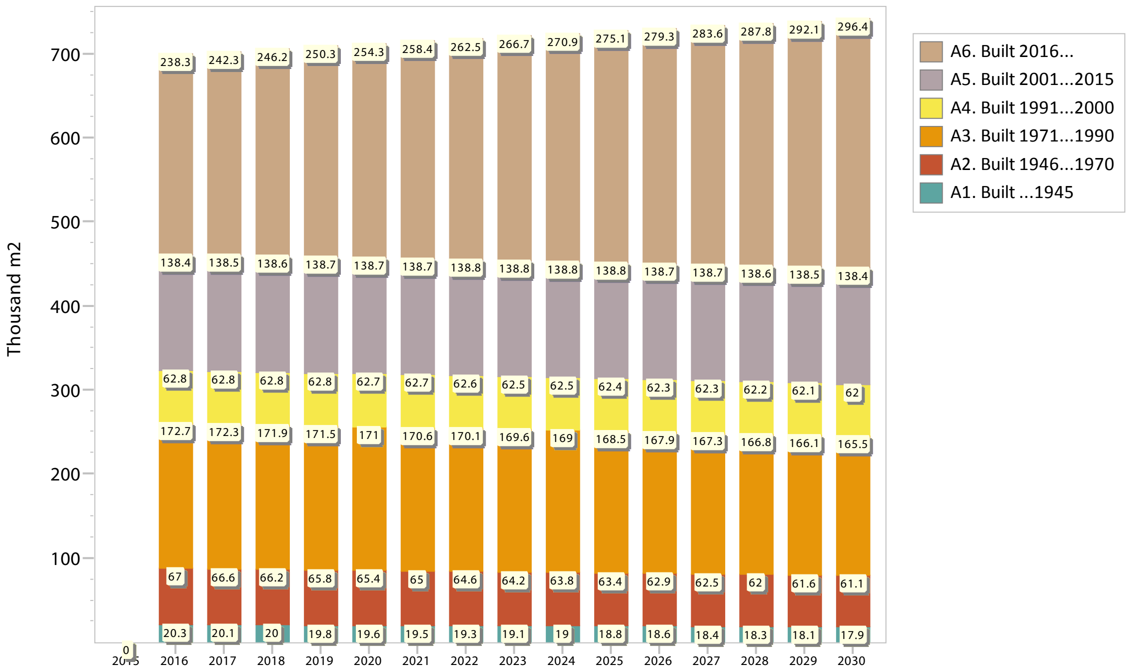


Figure 85 Total investment costs in the SLED ambitious scenario, 2015–2030

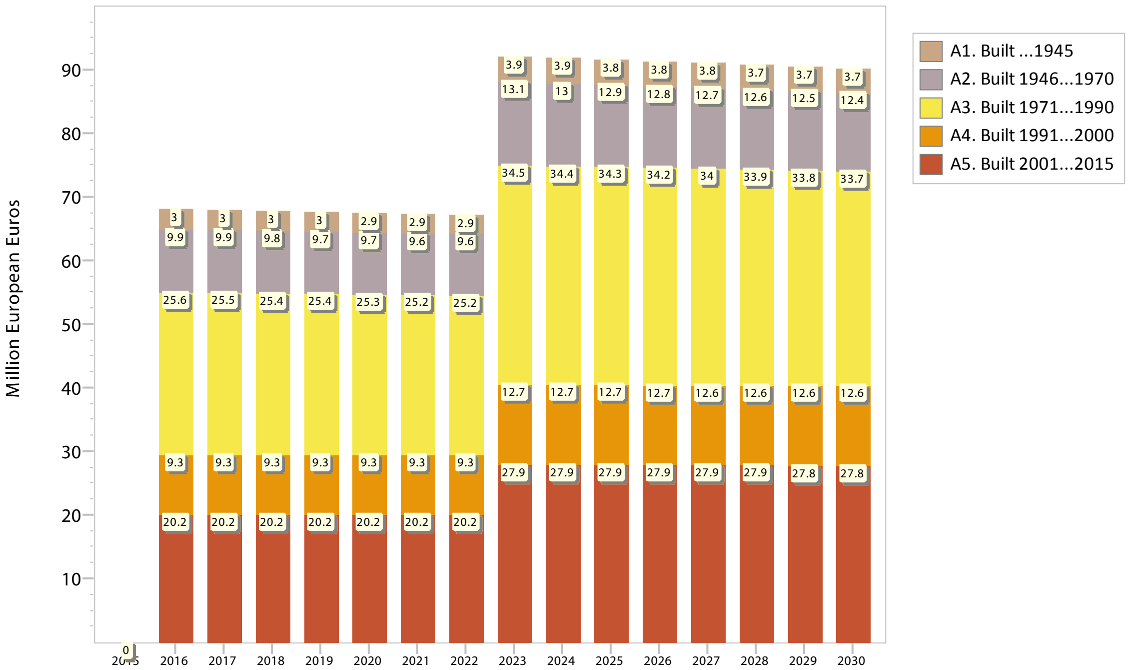
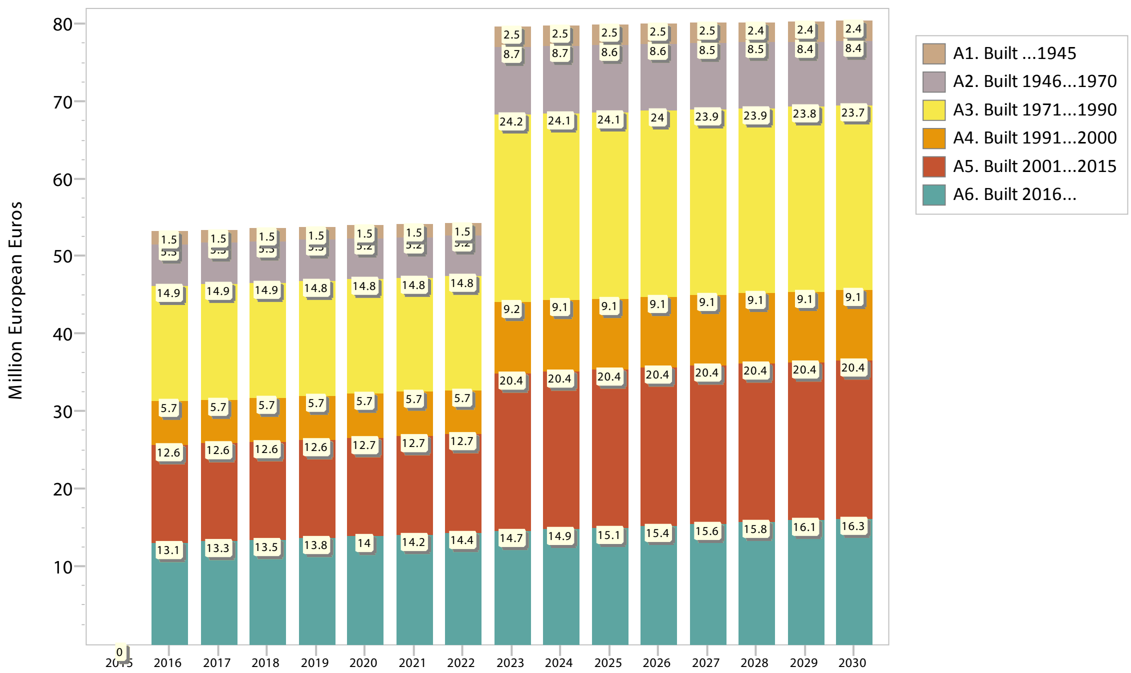


Figure 86 Incremental investment costs in the SLED ambitious scenario, 2015–2030



27 percent of the related total investment costs are supported in the case of small new buildings and around 29 percent in the case of medium-sized and large buildings. This level of support is approximately equal to the share of incremental investment costs in the SLED moderate scenario.

Figure 87 presents the costs to residential stakeholders of achieving compliance with the building code adopted in 2022 according to the SLED ambitious scenario. On average, these stakeholders will bear EUR 15 million of incremental investment costs per year as compared to the business-as-usual case.

Figure 88 shows the finance borrowed by residential stakeholders for the purposes of building retrofitting. Given our assumptions, the eligible costs of building retrofitting that investors would have to borrow would be around EUR 30 million per year, or around EUR 481 million over the modelling period. The eligible costs of more efficient construction would be around EUR 6.5 million per year, or EUR 97 million over 2016–2022.

Figure 89 illustrates the compensation paid by the government to commercial banks. Since the lending period is 10 years, the compensation paid by the government to commercial banks is at its highest in 10 years. After this, the amount of compensation for loans directed to building retrofitting stays almost the same until the end of the modelling period, while the compensation for loans directed to efficient construction decreases. Over the modelling period, the government provides EUR 204 million to commercial banks as compensation for subsidising low-interest loans for building retrofits, and EUR 64 million as compensation for low-interest loans for more efficient construction.

The government also provides grants for the retrofitting of existing buildings, as described in the assumptions in Section V. As Figure 90 illustrates, the value of these grants is around EUR 11 million per year, or EUR 179 million over the modelling period.

Figure 87 Private investments to achieve compliance with the building code in the SLED ambitious scenario, 2015–2030

Figure 88 Private (eligible) investments stimulated by low-interest loans in the SLED ambitious scenario, 2015–2030

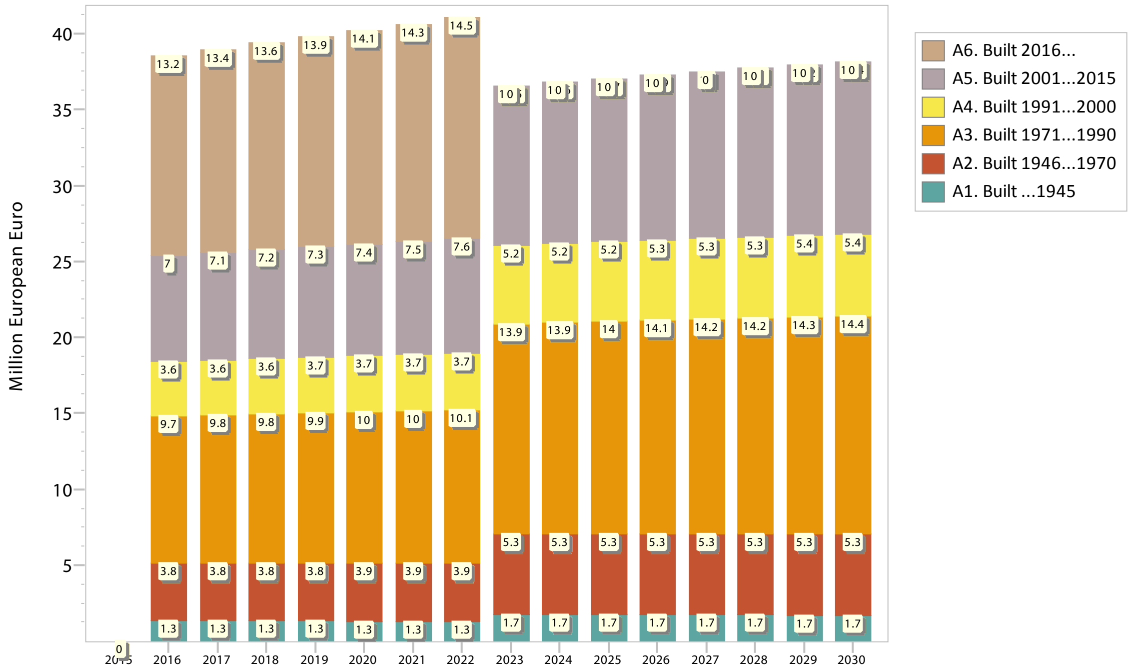


Figure 89 Cost to the government of low-interest loans in the SLED ambitious scenario, 2015–2030

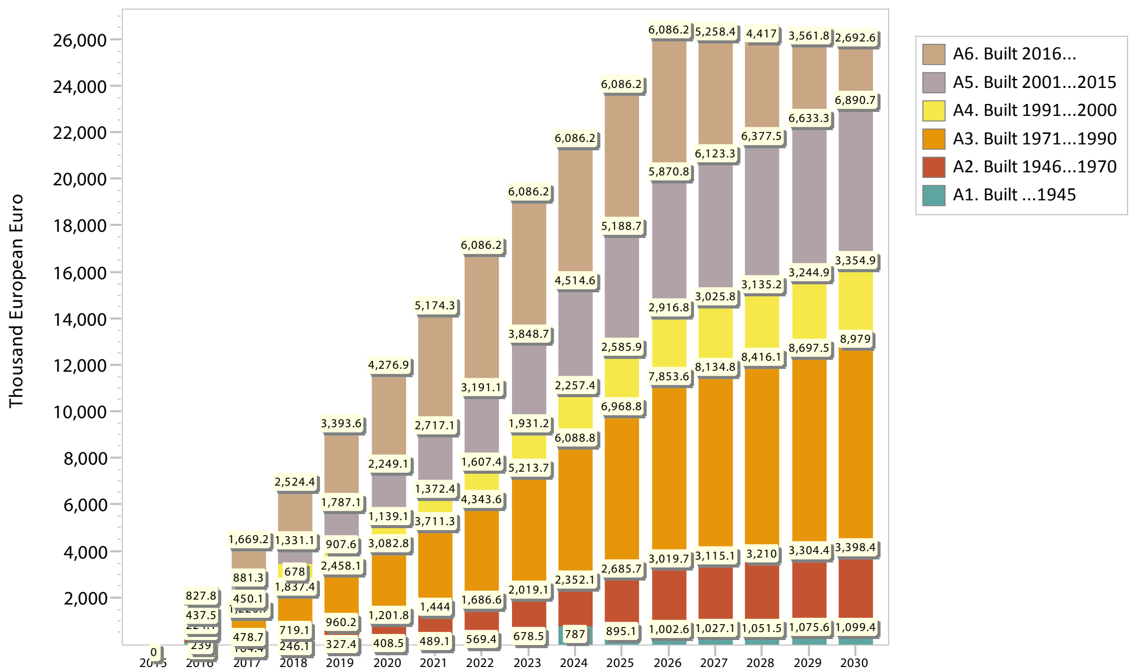
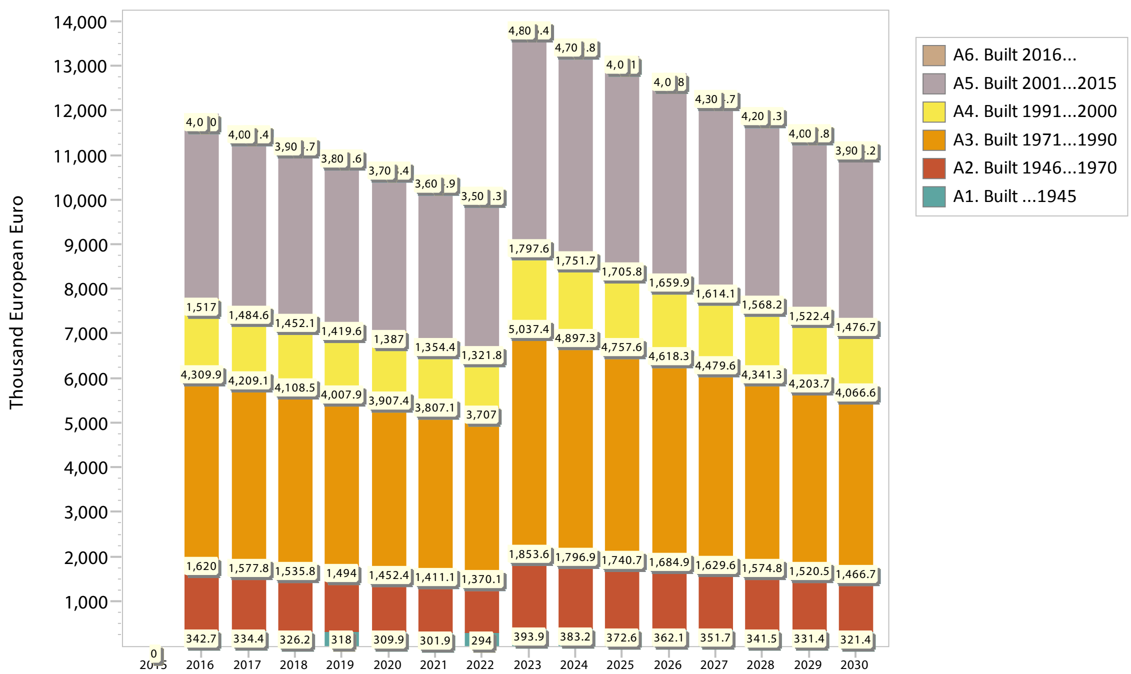


Figure 90 Cost to the government of grants in the SLED ambitious scenario, 2015–2030

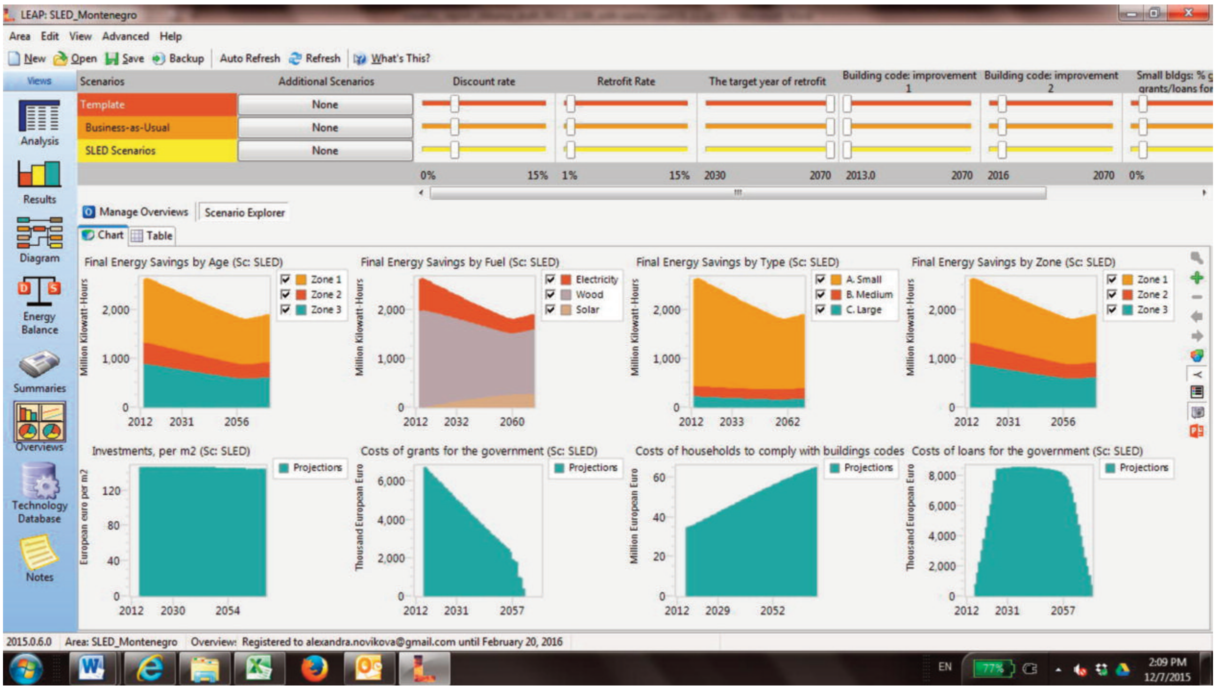


XIII. Sensitivity analysis and other possible scenarios

In the model, it is easily possible to change key assumptions within given intervals and thus to obtain results when a sensitivity analysis is needed. We pre-modelled such assumptions as the discount rate, the business-as-usual retrofitting rate, the target year in which the whole stock is retrofitted, the year in which the building code is adopted, the shares of loans and grants, and the share of eligible costs in the package of financial incentives. Figure 91 shows a screenshot of the sensitivity analysis in the model.

In addition to the SLED moderate and ambitious scenarios, we pre-modelled scenarios with only building codes, only grants, and only low-interest loans. The model allows for the easy changing of the contents of these scenarios.

Figure 91 Screenshot of the sensitivity analysis in the Montenegrin SLED model



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