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Smart energy city critical infrastructures

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Master of Energy Use and Energy Planning
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MASTER OF SCIENCE THESIS

Name:: **Lara Topol**

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Text: This assignment is realized as a part of the collaborative project “Sustainable Energy and Environment in Western Balkans” that aims to develop and establish five new internationally recognized MSc study programs for the field of “Sustainable Energy and Environment”, one at each of the five collaborating universities in three different WB countries. The project is funded through the Norwegian Programme in Higher Education, Research and Development in the Western Balkans, Programme 3: Energy Sector (HERD Energy) for the period 2011-2014.

A multitude of policy and technology developments have emerged in the last 10-15 years addressing sustainable development of cities, mitigation effects of climate change and creating better living conditions for citizens. Large cities are using their vast resources to search for their own development roadmap. However, a systematic approach does not exist yet and cities develop their plans individually. Small nations and developing economies will be first to suffer if caught unprepared in the midst of the fast developing struggle for resources among the large players. Here it is where smart energy cities have a potential to lead the transition - from fossil age into a bio-age.

The following subtasks are included:

- Literature review. Relevant literature is investigated.
- Economic analysis based on present and expect future costs.
- Conclusion and suggestions for future work,

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ABSTRACT

Smart energy city critical infrastructures

Smart energy cities have a potential to lead the transition from fossil age into the age of renewables. After a theoretical background is presented, of why the transition is necessary and what steps need to be taken in that direction, this paper brings insight into the paradigm of smart cities. The focus is set on the smart building as its fundamental building block. Fifteen cases of turning Norwegian and Croatian households into smart ones have been analyzed. Those are various combinations of consumption, generation and storage options. Expenses and revenues in case of implementing such smart households are presented by conducted cost and benefit analysis, as well as profitability of such projects.

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Keywords: smart, grid, city, building, energy, consumption, renewable, generation, storage, household, costs, benefits

PREFACE

Foremost, I would like to express my gratitude to Professor Slavko Krajcar and Professor Nenad Debrecin for their endless support and guidance, not only with writing of this thesis, but throughout my whole Master study. Secondly, I would like to thank Professor Ivar Wangesteen for his engagement during my stay at NTNU. Last but not least, I would like to thank my family and friends for providing me with love, care and understanding through the whole duration of my studies.

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Abbreviations

AC	*Alternating Current*
AMR	*Automatic Meter Reading*
DC	*Direct Current*
DSO	*Distribution System Operator*
EU	*European Union*
GHG	*Greenhouse gas*
HROTE	*Croatian Energy Market Operator*
HVAC	*Heating, ventilating and air conditioning*
IBM	*International Business Machines*
IEA	*International Energy Agency*
IoT	*Internet of Things*
LCOE	*Levelized cost of energy*
NASA	*National Aeronautics and Space Administration*
NECS	*Norwegian Energy Certificate System*
NPV	*Net Present Value*
NTNU	*Norwegian University of Science and Technology*
NVE	*Norwegian Water Resources and Energy Directorate*
OECD	*Organisation for Economic Cooperation and Development*
PV	*PhotoVoltaic*
ToD	*Time of Day*
US	*United States*
WEO	*World Energy Outlook*
ZEB	*Zero Energy Building*

1. Introduction

A multitude of policy and technology developments have emerged in the last 10-15 years addressing sustainable development of cities, mitigation effects of climate change and creating better living conditions for citizens. Large cities are using their vast resources to search for their own development roadmap. However, a systematic approach does not exist yet and cities develop their plans individually. Small nations and developing economies will be first to suffer if caught unprepared in the midst of the fast developing struggle for resources among the large players. Here it is where smart energy cities have a potential to lead the transition - from fossil age into the age of renewables.

1.1. Greatest threat to humankind

Urban living is beginning to take a central role in the direction in which humanity is evolving. Today, more than half of the population is living in urban environments. Urbanization, the demographic transition from rural to urban, is associated with shifts from an agriculture-based economy to mass industry, technology and service. For the first time ever, the majority of the world's population lives in a city and this proportion continues to grow. One hundred years ago, two out of every 10 people lived in an urban area. By 1990, less than 40% of the global population lived in a city, but as of 2010, more than half of all the people live in an urban area. By 2030, six out of every 10 people will live in a city, and by 2050, this proportion will increase to seven out of 10 people [1].

The effect of urbanization on the global climate has come into the limelight. It is due to the fact that, although there has been a lot of media coverage on global warming, only recently people are starting to experience what global warming brings on their own skin.

Global warming is caused mostly by increasing concentrations of GHG in the atmosphere and refers to global rise in average Earth's surface temperature. As the main consequence, climate patterns change. However, it is only one out of many aspects of climate change which includes major changes in precipitation, wind and temperature patterns that occur over several decades or longer.

Global temperature is a popular metric for summarizing the state of global climate. Climate effects are felt locally, but the global distribution of climate response to many global climate forcings is reasonably congruent in climate models; suggesting that the global metric is surprisingly efficient in quantizing what we all suspect to be true. Although local temperature fluctuation is considered to be common and quite normal, the average global temperature has been rising at the fastest rate in recorded history over the past 50 years. Scientists say that unless we curb the emissions that cause climate change, average temperatures could be 2 to 5 °C higher by the end of the century[2]. That has also been confirmed by the NASA projections of Earth's temperature and precipitation patterns from today throughout the year 2100. - revealing how "low" versus "high" emission scenarios would affect the planet's climate.

The NASA visualizations present projections of temperature and precipitation changes in the United States from 2000 to 2100 compared to the historical average from 1970to1999 under two different scenarios of future CO_2 emissions. The "higher emissions" scenario represents a fossil-fuel-intensive future in which concentrations of atmospheric CO_2 exceed 800 ppm[1] by the year 2100. The "lower emissions" scenario represents a less fossil-fuel-intensive future in which atmospheric CO_2 concentrations level off at around 550 ppm by 2100 (today, atmospheric CO_2 concentrations stand at around 400 ppm)[3].

While NASA's visualizations show significant warming in both scenarios, the projected average temperature change in the higher emissions scenario is nearly twice what is projected in the lower emissions scenario - at 4,5°C (versus "just" 2,5°C).Visualization can be accessed at the link[2] provided.

Changes in precipitation are expected to occur under both scenarios, but be more dramatic in the higher emissions scenario - with many dry areas getting dryer, while wet areas get wetter. Precipitation change visualization is also available at the link[3] provided.

Far-reaching effects on the Earth's climate patterns and on all living things will be triggered by this rise in average temperature[4]. Many of these changes have already started to take place.

- More energy is being pumped into tropical storms by the warmer water in the oceans, which makes them stronger and therefore more destructive. Higher sea levels intensify storm surges, flooding and erosion so that, even with storms of the same intensity, future hurricanes will cause more damage;

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[1] Parts per million - ppm - is commonly used as a measure of small levels of pollutants in air, water, body

[2] http://svs.gsfc.nasa.gov/vis/a000000/a004000/a004029/temp_mosaic.mp4

[3] http://svs.gsfc.nasa.gov/vis/a000000/a004000/a004028/precip_mosaic.mp4

- Probability of drought is increased by warmer temperatures. Risk of wildfires and worse drought conditions are caused by greater evaporation, particularly during summer and fall;
- In some areas, warmer temperatures increase the energy of the climatic system and lead to heavier rainfall. Scientists project that climate change will increase the frequency of heavy rainstorms, putting many communities at risk for devastation from floods;
- Smog pollution, pollen allergies and asthma would be increased by global warming in some areas. Local air quality problems are also common in hotter conditions;
- Melting of glaciers and ice caps will accelerate, and early ice thaw on rivers and lakes will is also occur, caused by rising global temperatures;
- More widespread outbreaks of infections like malaria, dengue fever[4], tick-borne encephalitis[5] and diarrheal illnesses arise in conditions of warming temperatures and alternating periods of drought and deluges. The global gush in infectious diseases is going to be a hardest hit for people living in poverty;
- More moisture is held and dumped by warmer atmosphere, which causes more extreme weather events, putting people's lives at risk;
- Thermal expansion of the oceans, partial melting of the West Antarctic and Greenland ice caps, as well as melting of most mountain glaciers will cause current rates of sea-level to rise. Some of the consequences are greater risk of flooding in coastal communities and loss of coastal wetlands and barrier islands; and
- The overall disruption of ecosystems is expected to occur with increase of global temperatures. Those species that cannot adapt will be pushed to extinction. Some researchers conclude that, if the current trajectory continues, around 1 million species could be obliterated by 2050.

Climate change is a very complex issue and it is hard to predict its full-scale impacts far in advance. However, year after year, scientists learn more about its effects on the planet and

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[4] Dengue fever (breakbone fever), caused by the dengue virus, is a mosquito-borne tropical disease. Symptoms include headache, fever, characteristic skin rash and muscle and joint pains. In the small proportion of cases it can evolve into life-threatening dengue hemorrhagic fever, which causes low levels of blood platelets and blood plasma leakage and internal bleeding. There is also a possibility of it developing into dengue shock syndrome that can be fatal because of low blood pressure symptom [69].

[5] Tick-borne encephalitis (TBE) is a viral infectious disease. It involves the central nervous system usually manifesting as encephalitis, meningitis, or meningoencephalitis. One of the most common symptoms is mild fever. In ten to twenty percent cases of infected patients, long-lasting or permanent neuropsychiatric consequences are noticed [70].

the projections made in the past are being confirmed. Certain consequences are agreed upon if current trends continue. Its negative effects will tackle our energy supply, water resources, agriculture and ecosystems, transportation, climate and health.

Global greenhouse gas emissions, broken down by the economic activities that lead to their production, are shown on Figure 1[5]:

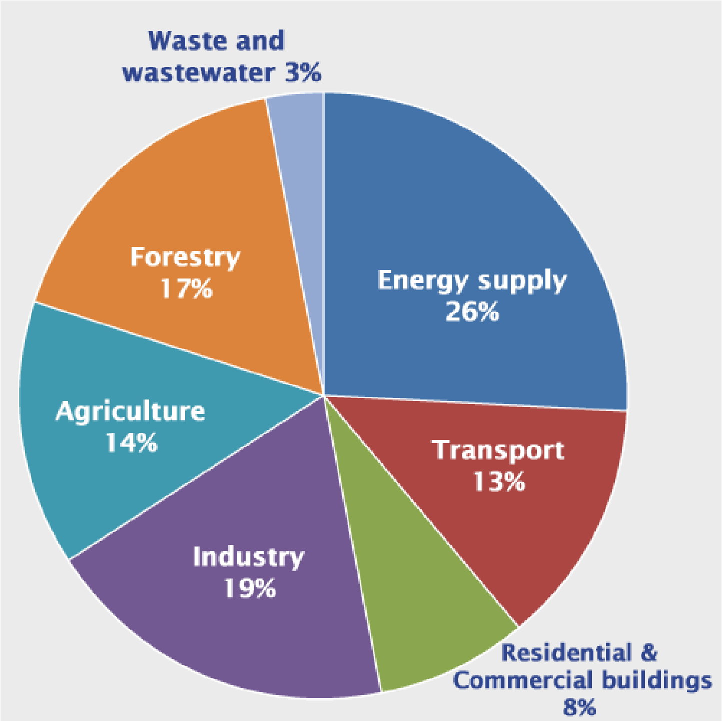

Figure 1 Global Greenhouse Gas Emissions by Source[5]

- **Energy Supply** (26% of GHG emissions) – This sector is the largest source of global greenhouse gas emissions. These emissions are released from burning of coal, natural gas and oil in processes of electricity and heat production;
- **Industry** (19% of GHG emissions) – Fossil fuels burned for on-site energy production are the primary source of GHG emissions from industry sector. Also included in this sector are emissions from metallurgical, chemical, and mineral transformation processes, which are not associated with energy consumption(Note: Emissions from electricity use are not accounted for in this, but covered in the energy supply sector);
- **Forestry** (17% of GHG emissions) –Carbon dioxide emissions from deforestation, fires or decay of peat soils and clearing of land are the main processes responsible

for GHG emissions from this sector. Carbon dioxide removed from the atmosphere by ecosystems is not included in this estimate[6];

- **Agriculture** (14% of GHG emissions) –Agricultural soils management, rice production, livestock, and burning of biomass are the main sources of GHG emissions from this sector;
- **Transportation** (13% of GHG emissions) - Fossil fuels burned for air, road, marine and railway transportation are the main sources of GHG emissions from this sector. World's transportation energy generation is 95% petroleum-based(mostly gasoline and diesel;
- **Commercial and Residential Buildings** (8% of GHG emissions) - On-site energy generation and burning fuels for heat and cooking in buildings and homes are responsible for GHG emissions from this sector. (Note: Emissions from electricity use are not accounted for in this, but covered in the energy supply sector); and
- **Waste and Wastewater** (3% of GHG emissions) - The largest source of GHG emissions in this sector is landfill methane (CH_4). Wastewater methane (CH_4) and nitrous oxide (N_2O) are the second responsible greenhouse gases. Plastics and synthetic textiles waste, made with fossil fuels, also cause minor emissions of CO_2.

Now that the main obstacle for sustainable development has been confirmed, global warming needs to be tackled on two main fronts – cutting pollution and expanding clean energy to significantly reduce CO_2 emissions.

Although there are obvious factors that justify the introduction of smart cities, they are not really taking off and not truly realizing the projected potentials. The need for affordable housing, traffic congestion, the rising energy costs, water scarcity and environmental targets or regulations are strong enough reasons to justify the transition to smart cities. However, the need for policy changes, limited capital availability, and piecemeal funding structures are preventing investment in smart cities. In addition, there are political uncertainties, which do not create a favorable environment for public and private investment. For example, the absence of long-term stability of carbon prices or the lack of public incentives for low carbon initiatives makes investment in low carbon technologies unattractive. Moreover, the inconsistency in international, national, and regional rules and regulations related to environmental policies does not help to scale initiatives. Finally, there is a lack of appropriate and systematic methodologies and metrics for reporting and verifying the investment returns due to smart city technologies.

The actual economic context is also not helping the introduction of the smart cities context. Depleted public finances from the recession are slowing down public investments. The financial situation, the unavailability of credit, and the new pressures and regulations on financial institutions to reduce risk exposure by building stronger deposit bases are limiting the available cash flows, slowing down private investments. Moreover, there are few alternative secondary markets to finance large smart city projects. Up to now, only grants coming from European Union funds or small local initiatives and local philanthropic capital allowed first trials to be run in Europe. Barriers to entry are not only economic or political. The geographical dispersion of the ongoing smart city projects, the multiple and complex technologies involved and their small size are not helping to create the required critical mass that might help show the viability of smart city deployments. The latter is seen as an increased risk to investors, who find it risky and difficult to aggregate individual and small-scale projects into large-scale investment vehicles. All of the above translates into a certain immaturity of the market as viewed from the private sector, which in turn is enhanced by the complexity of relationships with the public sector.

In addition, it is important to stress that almost all of the urban population growth in the next 30 years will occur in cities of developing countries. Nonetheless, on average, the rate of urban population growth is slowing in developing countries, from annual rate of roughly 4% from 1950-1975 to a projected 1,55% per year from 2025-2050 [1]. In high-income countries, on the other hand, the urban population is expected to remain largely unchanged over the next two decades. In these countries, immigration (legal and illegal) will account for more than two-thirds of urban growth. Without immigration, the urban population in these countries would most likely decline or remain static.

These facts deepen the problem of developing global smart cities infrastructure. Clearly, high-income countries are the ones having the means and the know-how. In addition, their economy is transparent and mature enough to marry the interests and needs of private and public sector. Without major economical shakedowns that occurred within the last decade, they probably would not even blink at the Second and Third World problems. In this case, slowly bleeding world’s economy is the great reminder that fossil-fuel-based economy has come to its sunset.

2. The Third Industrial Revolution

Mechanization of the textile industry triggered the first industrial revolution in Britain in the late 18^{th} century. The factory was born as the tasks previously done laboriously by hand in hundreds of weavers' cottages were brought together in a single cotton mill. In the early 20^{th} century, as the moving assembly line was mastered by Henry Ford, the second industrial revolution came and started the age of mass production [7]. The first two industrial revolutions served us well as we became urban and richer. Now, as the third industrial revolution is on its way, how do we know what to expect?

2.1. Why is the Third Industrial Revolution necessary?

When new communication technologies converge with new energy regimes, the great economic revolutions in history take place. More expansive and integrated trade is made possible by the new energy revolutions. The new complex commercial activities are made possible by the new energy flows, accompanied by communication revolutions that they are managed with.

Today we are all witnesses of industrial civilization being at the crossroads. Industrial way of life, made up of oil and the other fossil fuel energies are sun setting. Technologies that are made from and propelled by these energies are obsolete. Second Industrial Revolution is threatening the viability of life on Earth as the industrial induced CO_2 emissions are rising.

The main drivers of global energy demand are population and economic growth. The projection of the world's population growth is 1,7 billion between 2012 and 2035. During that course of time, it is expected that the real income will more than double [8]. Even with new climate policies and shifting towards less energy-intensive activities in fast-growing economies, energy demand is likely to increase. In its Energy Outlook 2035, BP predicts increase of energy consumption by region (Figure 2) and by fuel (Figure 3). These show that non-OECD[6] countries will be responsible for energy consumption increase generally based on coal as a primary energy source.

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[6] The Organization for Economic Co-operation and Development (OECD) – was founded in 1961 to stimulate economic progress and world trade. It's an international economic organization of 34 countries committed to democracy and market economy: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea,

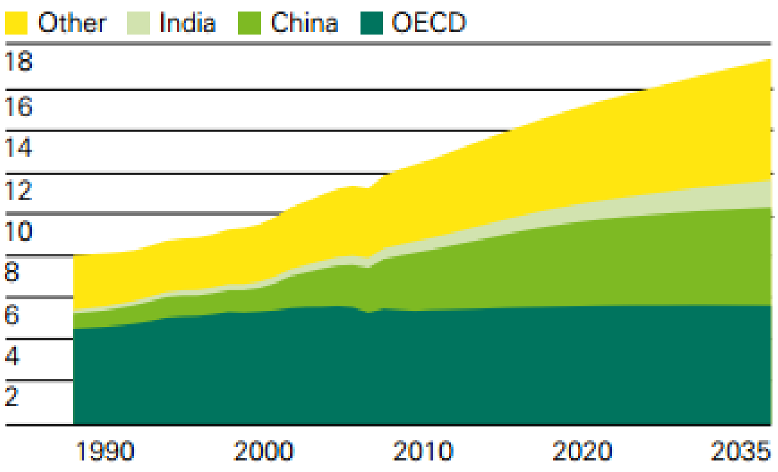

Figure 2 Energy consumption by region (billion tons of oil equivalent)[9]

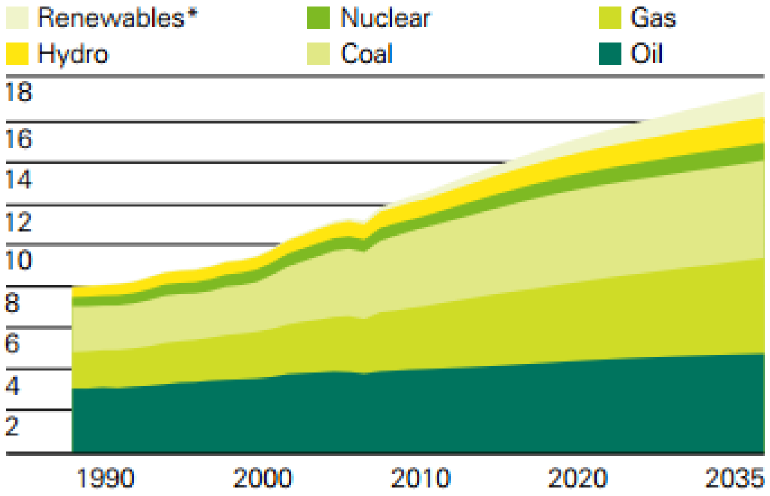

Figure 3 Energy consumption by fuel (billion tons of oil equivalent) [9]

The increase in gas consumption mainly addresses the new gas source called shale gas. This term refers to natural gas trapped within shale formations. These are fine-grained sedimentary rocks, rich in sources like petroleum and natural gas. Over the past decade, access was gained to large volumes of shale gas that were previously uneconomical to produce. This was made possible by combination of horizontal drilling and hydraulic fracturing. In the US, the production of natural gas from shale formations has completely transformed the natural gas industry.

When it comes to burning natural gas versus burning coal or oil, significantly lower levels of carbon dioxide (CO_2) and sulfur dioxide (SO_2) are emitted. Natural gas combustion, when used in efficient combined-cycle power plants, can emit less than half as much of CO_2 as coal combustion, per unit of electricity output.

Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States[71].

However, shale gas production brings its own environmental concerns. The fracturing of wells requires significant amount of water. In some areas, this could affect availability of water for other uses, as well as aquatic habitats [10].

BP's analysis suggests that global CO_2 emissions from fossil fuels may be 29% higher in 2035 than they were in 2012 [8], partly as a consequence of coal use in rapidly growing economies of non-OECD countries. More aggressive energy policies and technologies could lead to slower growth in CO_2 emissions than expected but this would still not be enough to limit warming to no more than 2°C, the threshold recognized by governments as limiting the worst impacts of climate change. The International Energy Agency has acknowledged that its 450 Scenario[7]which would put the world on a lower-carbon trajectory, looks increasingly unlikely. There are several reasons, in addition to growing energy demand, why achieving substantial and rapid GHG emissions reductions will be challenging. Some potentially important lower-carbon technologies – including nuclear energy, carbon capture and storage, and electric vehicles – still face significant technology, logistical, political and cost challenges[11]. Moreover, worries about the cost of renewable technologies have led some governments to reduce their levels of support. In the meantime, the GHG intensity of oil and gas extraction and production looks set to increase.

Energy sector is the source of one fourth of global GHG emissions [5].With transport and industry under its wing, it will be crucial in achieving climate change goals. Various national initiatives have the potential to limit the growth of energy-related CO_2 emissions, such as European debate on 2030 energy and climate targets, President's Obama Climate Action Plan in the United States, coal limitation plan in the China's domestic energy mix, Japan's discussions on a new energy plan [12]. In IEA central scenario[8], energy-related CO_2 emissions still rise by 20% until 2035, although the impact of governments' announced measures are taken into account. They allude energy efficiency improvements, renewable resources support, and fossil-fuel subsidies reduction. In some cases, carbon pricing is also put into effect, but energy-related CO_2 emissions are still expected to rise by 20% until 2035[8]. After consolidation of all of these measures, long-term average

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[7] 450 Scenario - is a scenario presented in the World Energy Outlook. It sets a target of limiting the global increase of temperature to 2°C by obtaining GHG concentration at around 450 parts per million of CO_2 in the atmosphere[13].

[8] The central scenario of the World Energy Outlook 2013 (the New Policies Scenario) – broadly serves as the IEA baseline scenario and implies 650 ppm of the atmospheric concentration of CO_2. Policy commitments and plans already announced and validated are taken into account in this scenario. This also includes national pledges to reduce GHG emissions and plans to cancel all fossil-energy subsidies. Naturally, some of the measures for implementation of these commitments have yet to be identified or announced [13].

temperature increase is projected to be as high as 3,5 °C, which is far more than the internationally agreed 2°C target. According to authors cited by the IEA, these levels of warming would cause damaging sea-level rise and disruptive climate changes. There is also an increased possibility of triggering feedbacks in the global carbon cycle [11].

The 2DS falls in place with the World Energy Outlook 450 Scenario. Energy system described by this scenario is coherent with an emissions trajectory that gives an 80% chance of limiting average global temperature increase to 2°C. Energy-related CO_2 emissions would be cut by more than half in 2050 (in comparison with 2009) and continue to fall thereafter. Importantly, as the 2DS acknowledges, transforming the energy sector is vital, but not the only solution. The goal can be achieved only with simultaneous reduction of GHG emissions in the non-energy sectors[13]. Sector contributions to emissions reductions needed to achieve the 2DS goal are shown on Figure 4.

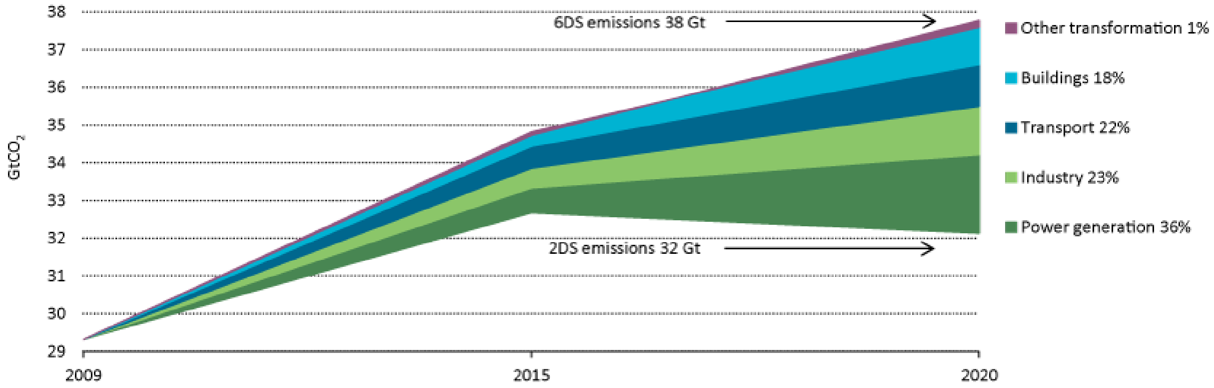


Figure 4 Sector contributions to emissions reductions [14]

Climate and emission targets are expressed as round-number integers. This can lead to false conclusion that they can be defined with great precision. On the contrary, it has to be clear that little more than 450 ppm might be safe and that little more than two degrees of warming might not lead to complete climate disaster. We might still have a decade rather than the IEA's five years to dither around. On the other hand, perhaps a limit of 350 ppm, that we now have just passed, should have been our target[15]. Seems like carbon cycles have already started to kick in (take for instance changes happening in the Amazon or in the Arctic).This awakens the doubt of having five years to act twenty years ago. Our limits are uncertain. Our models and best-laid plans will not survive unscathed from their first contact with reality. Nevertheless, as the WEO13 report [12] makes it clear, we do know exactly when to act: now.

2.2. Five pillars of the Third Industrial Revolution

Today, a Third Industrial Revolution is at rise, as Internet communication technology is converging with renewable energies[16]. It is enabled by the creation of a renewable energy regime, loaded in buildings and partially stored in the form of hydrogen or some other energy storage option, distributed via smart grid, and connected to plug in zero emission transport. The entire system is integrated, seamless and interactive. New opportunities for cross-industry relationships are created by this interconnectedness. A new era of "distributed capitalism" is being brought by the Third Industrial Revolution [17]. New energy players will be millions of existing and new homeowners and businesses. This process will jump-start a new technology revolution, create millions of green jobs, mitigate climate change and dramatically increase productivity.

This Third Industrial Revolution rests on the back of the five pillars presented in the Figure 5. Synergies between them create a new economic paradigm that can transform the world's economy and provide sustainable development.

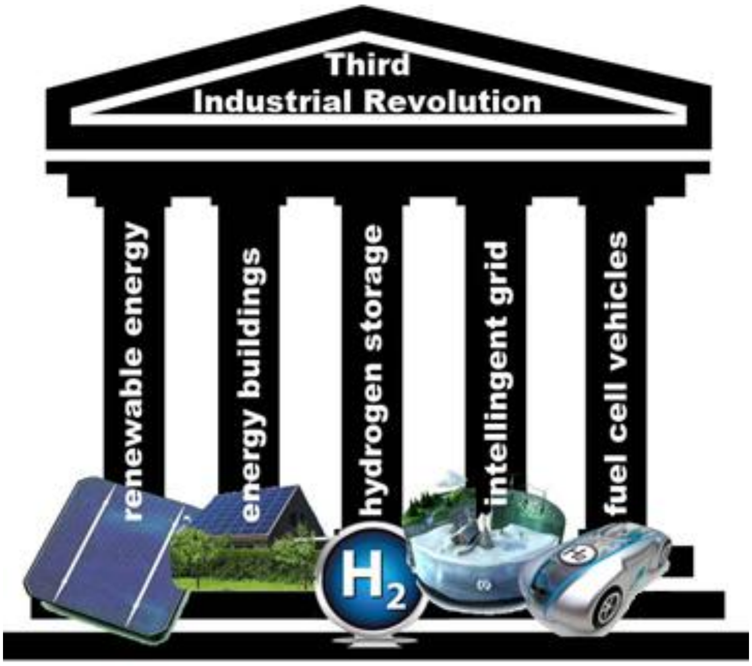


Figure 5 Five pillars of the Third Industrial Revolution

The five pillars of the Third Industrial Revolution are [16]:

- **Shifting to Renewable Energy**: First of the five pillars of the Third Industrial Revolution is made out of solar, wind, hydro, geothermal, ocean waves, biomass and other renewable forms of energy. Although they are growing rapidly, their percentage in the global energy mix is still quite low [9]. Their widespread introduction into the market will be made possible by governments' mandate targets and benchmarks;

- **Buildings as Power Plants**: New technological breakthroughs make it possible to design and construct buildings that create their own energy from locally available renewable energy sources such as wind, sun, garbage, hydro and geothermal, agricultural and forestry waste, ocean waves and tides. They should be able to produce enough energy to cover their own needs and then share the surplus;
- **Deploying Hydrogen and other storage technologies** is necessary because of the nature of renewable energy production. In every building and throughout the infrastructure intermittent energies will be stored in order to maximize renewable energy and to minimize cost. Some of the storage options, such as batteries or differentiated water pumping, can offer limited storage capacity. However, hydrogen is one storage medium that can be relatively efficient and is widely available. It can store all forms of renewable energy to assure stable and reliable supply is available for power generation and for transport;
- **Using Internet technology to transform the power grid** into energy sharing Internet. The idea is based on the same principle as sharing information produced on our own with each other across the Internet. This reconfiguration of the power grid, providing energy production and sharing by businesses and homeowners, is being tested within many pilot projects in Europe and United States. The new smart grids would revolutionize the way electricity is produced and delivered to the consumers; and
- **Transitioning the transport fleet to electric, plug in and fuel cell vehicles** which are able to make market-based electricity transactions on a smart grid. In order to produce hydrogen to power fuel cell vehicles or power electric plug-in cars, electricity produced by renewable energy sources in buildings will be used. The electric plug in vehicles can also help decrease peak demand, since they are able to sell stored electricity back to the main grid in the peak hours and charge in the off-peak hours.

In addition to these five pillars, the importance of energy efficiency should also be mentioned. Several aspects of the energy challenge are addressed by greater energy efficiency. Because less energy is needed it helps with affordability. It also provides greater security as it reduces dependence on imported energy. And finally, as it improves emissions reduction, it helps achieve sustainability.

3. Smart city

Economical and technological changes, caused by the globalization, challenge cities to simultaneously combine sustainable urban development and competitiveness. Such challenge will surely trigger housing, economy, cultural, social and environmental issues and tackle with urban quality of life.

IBM Corporation in November 2008 issued the concept of "Smart Earth". The principle of Smart Earth is that sensors are embedded in the railways, bridges, tunnels, roads, buildings, water systems, dams, commercial equipment and medical equipment, and then physical facilities can be perceived, so information technology extends into physical world, constructing an "Internet of Things" (IoT). Figure 6 shows a symbiotic interaction among the real/physical, the digital, virtual worlds and society in this concept.

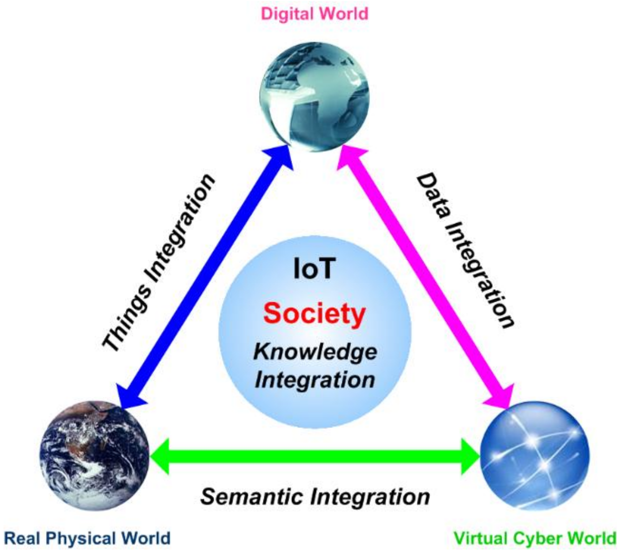


Figure 6Internet of Things concept [18]

Smart things and objects in the IoT concept will be active participants in social, business and information processes. By exchanging data and information “sensed” about the environment, they are able to interact and communicate with the environment and among themselves. They will influence the real/physical world by automatically reacting to the events that take place in it. With or without the need for direct human intervention they run processes that trigger actions and create various services.

Using standard interfaces that provide the necessary link via the Internet, services will also be able to interact with smart things and objects. That way they could receive information associated with them and then accordingly adopt their state. Security and privacy issues, arisen from implementing such technologies, should be addressed with great severity.

Computers and cloud computing will manage people, machines, equipment, etc. This platform will enable people's lives to be managed dynamically with great precision in order to get smarter and improve the relationship between them and their environment [19].

As the Figure 7 pictures, Internet of Things has potential to drive energy efficient applications such as the smart grid, demand side management, smart transport, energy efficient smart buildings and renewable resources. It will also provide contribution to major fuel savings, hence reduce carbon emissions.

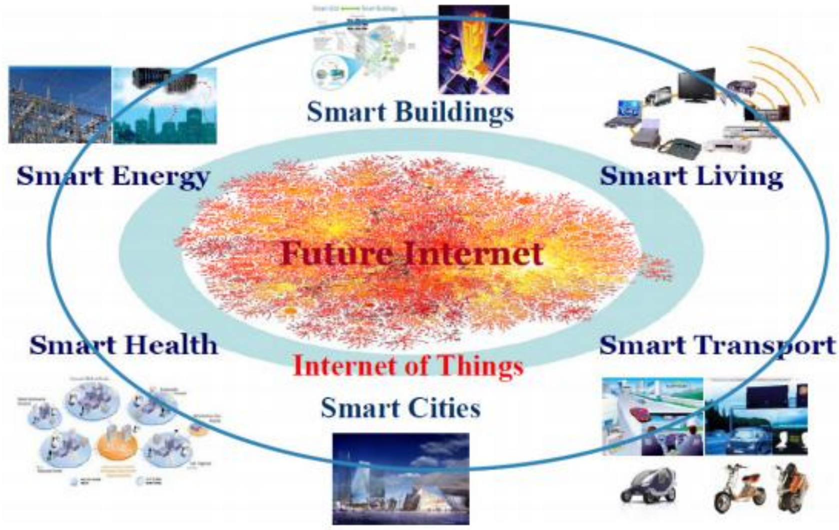


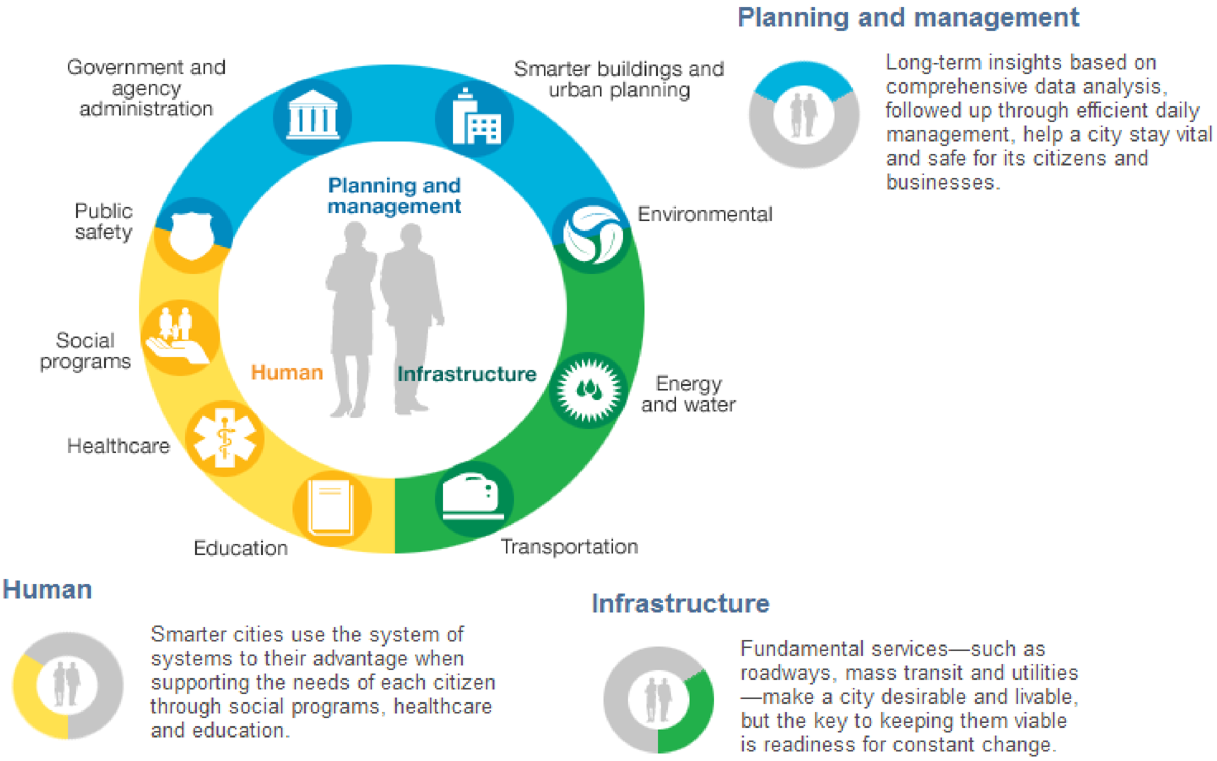
Figure 7IoT and smart environments creation [20]

By the middle of 2009, the number of people living in urban areas (3,42 billion) had surpassed the number living in rural areas (3.41 billion) and since then the world has become more urban than rural [21]. Most people living in cities, the main application of Smart Earth model is "Smart City" system. "Smart city" is defined by IBM as the use of information and communication technology to sense, analyze and integrate the key information of core systems in running cities. At the same time, smart city can make intelligent response to different kinds of needs, including daily livelihood, environmental protection, public safety and city services, industrial and commercial activities [22].

3.1. Smart city infrastructure

What makes a city? IBM suggests that there are three main components as shown on Figure 8. This paper will only address the ones on the right hand side of the presentational circle:

- **Smarter buildings and urban planning -** Managed through a central repository, buildings fit with smart sensors and control systems can measure, sense and see the condition of practically everything in them. Smarter buildings lower maintenance and energy costs, and improve reliability and sustainability. In addition to that, active smart buildings equipped with renewable energy source such as PV panels lower their expenditures even further;
- **Environmental -** Sustainable development embrace a new objective: optimize operations to minimize environmental impact and improve social outcomes in a manner that also maximizes performance;
- **Energy and water** - The smart grid uses digital sensors, advanced communication networks and sophisticated analytics to help utilities understand demand in near real time, more effectively manage supply and demand, and put greater control of energy usage into the hands of consumers; and
- **Transportation -** Intelligent transportation systems improve capacity, enhance travel experiences and make moving anything safer, more efficient and more secure. Traffic managers gain citywide visibility to help alleviate congestion and rapidly respond to incidents. In addition, transportation fleet should be “green”, running mainly power electric plug-in cars or fuel cell vehicles.



Long-term insights based on comprehensive data analysis, followed up through efficient daily management, help a city stay vital and safe for its citizens and businesses.

Smarter cities use the system of systems to their advantage when supporting the needs of each citizen through social programs, healthcare and education.

Fundamental services—such as roadways, mass transit and utilities—make a city desirable and livable, but the key to keeping them viable is readiness for constant change.

Figure 8 Smart city main components[23]

3.2. Smart building

Worldwide, the building sector is responsible for 40% of energy consumption [24] so there is a huge potential in energy savings. It can be achieved by implementing various energy efficiency measures such as building envelope improvement, switching to new generation of high efficiency appliances and heating solutions. There is also a huge financial savings potential by implementing demand response since 20% of capacity for electricity generation is being used for only 5% of the time[25].

From the perspective of energy efficiency and utilizing demand response, building sector can be broken down as presented on Figure 9. This breakdown is based on building's purpose but it also reflects different energy consumption patterns and energy efficiency measures that can be implemented. This paper will concentrate mostly on turning households (residential buildings) into smart dwellings that save and produce electricity by implementing smart appliances, PV modules and interface that allows two-way communication between the smart building and the energy distribution network.

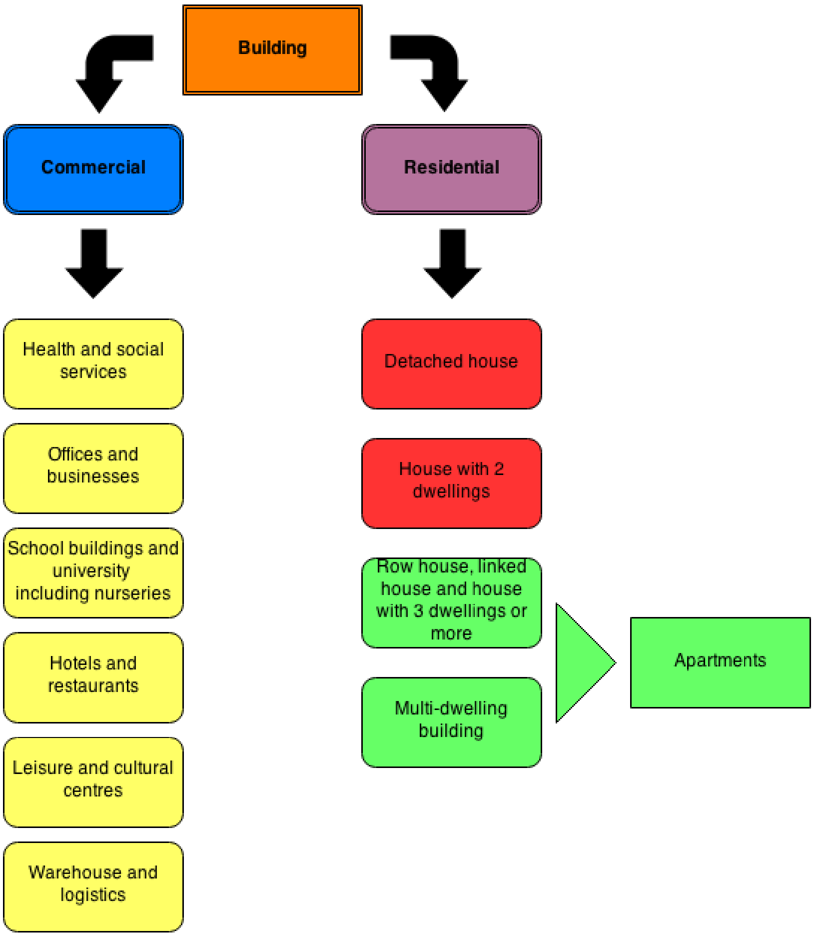


Figure 9 Building sector breakdown

Smart building is the basic building block of the smart city. But what makes a building smart? The definition of the term has been constantly evolving. It started three decades ago as a building with implemented passive energy efficiency measures. Later on, it was a building with central, computer operated infrastructure system. Today it implies all previous with the addition of networked appliances, advanced energy management and renewable energy sources.

Smart buildings can communicate with the energy distribution network which they can monitor and receive signals from. They adapt to conditions in the network by decreasing or increasing their energy consumption. Smart buildings also communicate between themselves, exchanging both information and energy generated by on-site renewable energy sources (mostly PV). Energy generated from renewables can be used within the building or sold on the market. That decision is made by an algorithm that takes into account electricity market price, building’s present consumption and user settings. If any energy storage capacity is present, it should also be accounted for as a grid asset.

In general, the smart building consists of [25]:

- Sensors – monitoring of selected parameters and submit data to actuators;
- Actuators – which perform physical actions (i.e. open or close window shutters, turn on appliance, etc.);
- Controllers – monitoring inputs from sensors, managing units and devices based on programmed rules set by user;
- Central unit – used for programming of units in the system;
- Interface – the human-machine interface to the building automation system;
- Network–communication between the units (RF, Bluetooth, wire); and
- Smart meters–two-way, near or real-time communication between customer and utility company.

Today's buildings incorporate principles of energy efficiency. This is manifested in choice of materials, architecture, construction procedures and other passive and active energy efficiency measures. However, without a system for real time monitoring, control and communication with the grid, the building cannot fully adapt to grid conditions.

3.2.1. Zero energy building

A zero energy building (ZEB) is one step further from the smart building concept. Buildings that meet all of their requirements for energy from locally available, low-cost, renewable sources are the basic idea of the ZEB concept. At the level that is stricter in approach, ZEB should have enough renewable energy production on site to cover or exceed its annual energy use.

When on-site generation isn't enough to meet the load requirements, ZEB would use traditional energy sources such as natural gas and electric utilities. Possible generated excess of electricity is exported to the utility grid, if the on-site generation would exceed building's load requirements. By using the power grid to balance energy production and generation, excess production can offset later energy use. That is why achieving off-grid ZEB in today's market conditions would be almost impossible, as the current energy storage technologies are yet to become efficient and affordable.

Depending on the boundary and the metric, ZEB can be defined in several ways. Appropriate definition depends on the project goals and the preferences of the design team and building owner. For example, energy costs are usually what mostly concerns building owners. On the other hand, NGOs are typically interested in primary energy source and concerned with national energy numbers. A building designer is going to be interested in site energy use for energy code requirements. Finally, emission reductions are of interest for those who are concerned about pollution. Four commonly used definitions are [26]:

- **Net Zero Site Energy**: when accounted for at the site, this type of ZEB's yearly energy production is equal to or greater than its yearly energy consumption;
- **Net Zero Source Energy**: when accounted for at the source, this type of ZEB's yearly energy production is equal to or greater than its yearly energy consumption. Source energy refers to the amount of primary energy needed to generate and deliver the energy to the site. When calculating building's total source energy, appropriate site-to-source conversion multipliers have to be applied both on imported and exported energy;
- **Net Zero Energy Costs**: with this type of ZEB, money instead of energy equilibrium needs to be accomplished. Building owner gets paid by the utility for the energy exported to the grid from the building's generation capacities. Also, the

utility gets paid by the building owner for the energy imported from the grid and various energy services; and

- **Net Zero Energy Emissions**: with this type of ZEB, renewable, emissions-free energy produced on site should cover or exceed energy consumption from emissions-producing energy sources.

There has been a lot of polemics when it comes to ZEB definition. One point of view is the location of renewable energy generation. Different renewable supply options for ZEB are shown on Figure 10 and explained in Table 1.

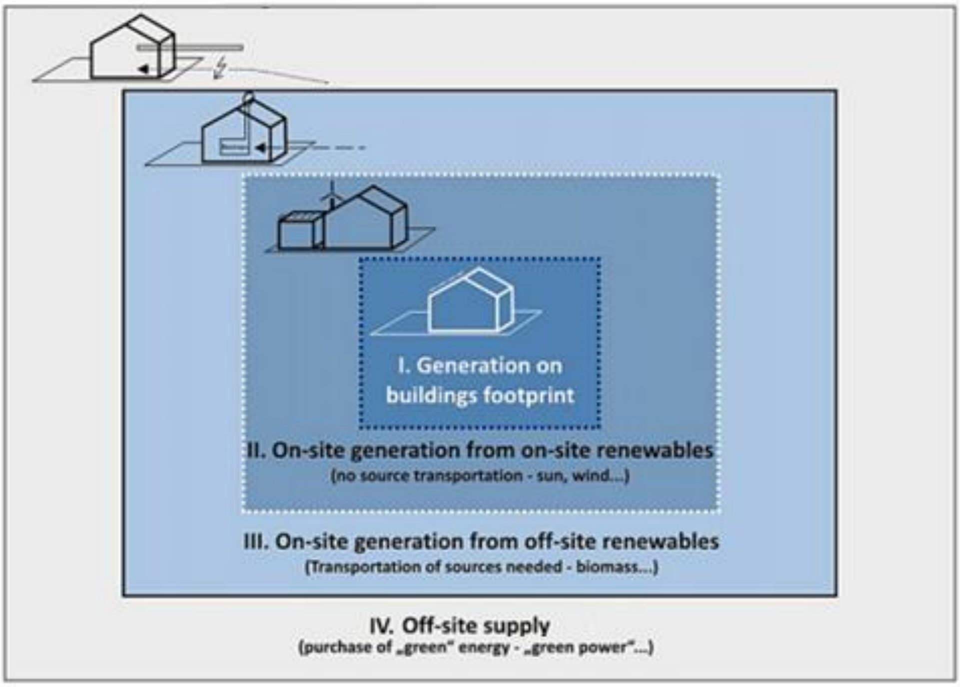
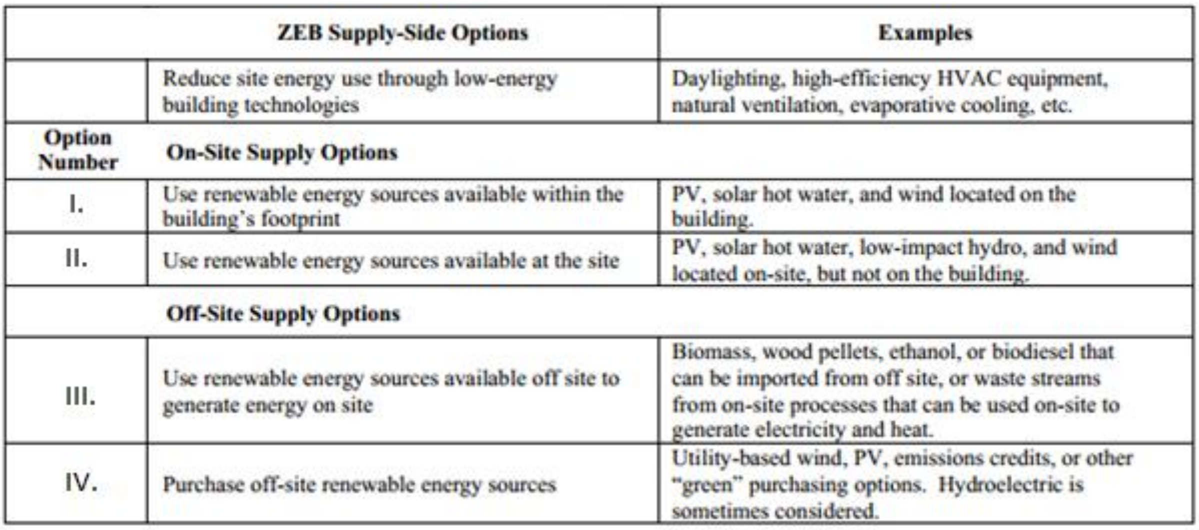


Figure 10 Overview of possible renewable supply options[27]

Table 1 ZEB Renewable Energy Supply Option Hierarchy[26]



	ZEB Supply-Side Options	Examples
	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
Option Number	**On-Site Supply Options**	
I.	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building.
II.	Use renewable energy sources available at the site	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building.
	Off-Site Supply Options	
III.	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
IV.	Purchase off-site renewable energy sources	Utility-based wind, PV, emissions credits, or other "green" purchasing options. Hydroelectric is sometimes considered.

The fourth supply option is different from all of the others because it implies renewable energy generation off-site or so-called “green” energy purchase. Of course, by the physical properties of electrical current, consumer is not actually being supplied by 100% renewable energy since power flow in the grid cannot be directed. He is paying the price as if all of his electric energy demand is being met by the renewable energy sources.

Trønder Energi Marked AS was among the first Norwegian electricity suppliers to attach origin documentation and sell “green”, 100% renewable electricity. Today they are offering 100% renewable electricity tariff for households. This agreement is equivalent to a spot contract, but with 100% renewable electricity. They guarantee that the same amount of electricity that is consumed is produced from a 100% renewable energy. This costs NOK 12 more in fixed amount per month than the regular spot deal. Fixed fee is NOK 59 per month and the premium of 1,93 øre/kWh is added due to costs associated with the purchase of electricity certificates. This agreement applies only to systems with total consumption less than 50.000 kWh/year.

The amount of “green” energy available is being sized by electricity certificate market.

3.2.2. Electricity certificate market

Electricity certificates provide financial support to producers of renewable electricity in Sweden and Norway. The electricity certificate system is market-based and aims to increase the production of electricity from renewable sources in a cost-effective way. The Norwegian-Swedish electricity certificate market was established on 1st of January 2012. Norway and Sweden have a common goal of increasing the renewable electricity production by a total of 26,4 TWh from 2012 to the end of 2020. This corresponds to the power consumption of more than half of all Norwegian households.

Norway and Sweden are each responsible for financing 13,2 TWh in the certificate system, regardless of where the new production capacity is established. The electricity certificate scheme will contribute to the achievement of the countries’ goals under the EU’s Renewables Directive. The common electricity certificate market is due to continue through the end of 2035.

Despite the fact that Sweden and Norway are to finance the common goal in equal parts, the cost of electricity per kilowatt-hour (kWh) differs in the two countries. Different quotas and a common electricity certificate price mean that the cost per kilowatt-hour differs. Illustration of the electricity certificate market is shown on Figure 11.

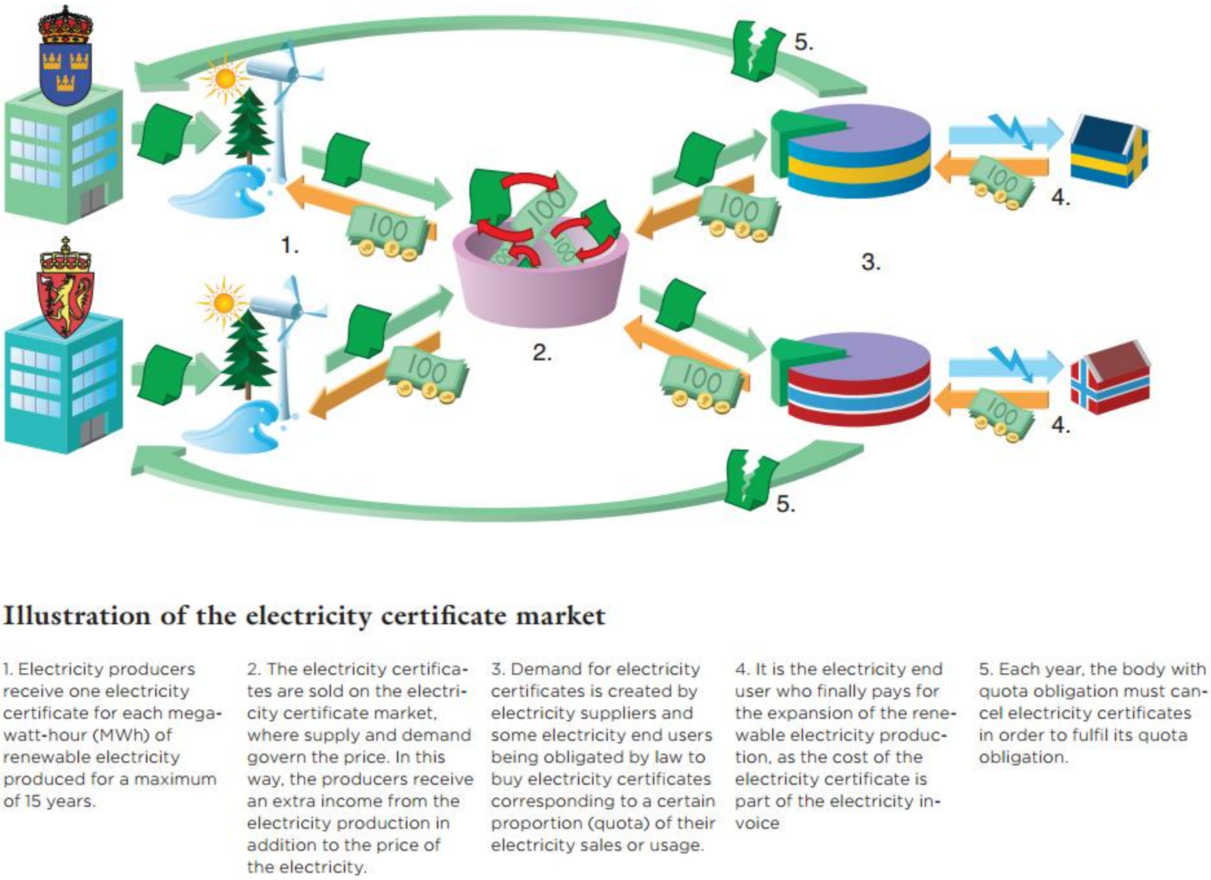


Illustration of the electricity certificate market

1. Electricity producers receive one electricity certificate for each megawatt-hour (MWh) of renewable electricity produced for a maximum of 15 years.

2. The electricity certificates are sold on the electricity certificate market, where supply and demand govern the price. In this way, the producers receive an extra income from the electricity production in addition to the price of the electricity.

3. Demand for electricity certificates is created by electricity suppliers and some electricity end users being obligated by law to buy electricity certificates corresponding to a certain proportion (quota) of their electricity sales or usage.

4. It is the electricity end user who finally pays for the expansion of the renewable electricity production, as the cost of the electricity certificate is part of the electricity invoice

5. Each year, the body with quota obligation must cancel electricity certificates in order to fulfil its quota obligation.

Figure 11 Illustration of the electricity certificate market [28]

Power producers are issued electricity certificates corresponding to the production from power plants approved by Norwegian Water Resources and Energy Directorate (NVE) and the Swedish Energy Agency. Eligible new power plants receive one electricity certificate per megawatt-hour (MWh) of electricity generated.

NVE manages the electricity certificates in Norway in cooperation with Statnett (system operator in the Norwegian energy system) which acts as the register coordinator. Statnett issues the electricity certificates, and maintains an elec-tricity certifi-cate register showing the amount of electricity certificates held by power producers, suppliers, and consumers.

Electricity suppliers and some end-users of electricity are obligated by law to buy electricity certificates corresponding to a certain proportion (quota) of their electricity sales or usage. This creates the demand for electricity certificates in the market. Electricity-intensive industries have an electricity certificate cost only for the proportion of the electricity which is not used in the manufacturing process.

Each year, the market participants with an obligation to buy electricity certificates must redeem electricity certificates in order to fulfill their obligation. In Norway suppliers with an obligation to redeem electricity certificates must confirm the pre-reported figures in the Norwegian Energy Certificate System (NECS), by 1 March each year. The figures are available for confirmation from 16th of February each year. Suppliers then have until 31st of March to acquire the necessary electricity certificates to meet their electricity certificate obligation.

The system is financed by electricity end-users, as the costs of certificates are added to the electricity bill. In this way, electricity end-users in Sweden and Norway contribute to paying for the increase in renewable electricity production.

The price of electricity certificates is determined by supply and demand in a common market for Norway and Sweden. Average energy certificate price for the month of April 2014 was NOK 160,56 [29]. Certificate demand is determined by power consumption and the set proportion of electricity for which certificates must be purchased each year. Supply depends on investment in eligible electricity production.

The electricity certificate system is neutral with regard to technology. This means that all technologies defined as renewable energy sources pursuant to the renewables directive receive the same subsidy amount.

In 2013, power consumers in Norway had to pay for electricity certificates corresponding to 4,9% of their electricity consumption. The actual additional costs are determined by the electricity certificate price, which will vary according to supply and demand. If the electricity certificate price is NOK 200, a family using 20.000 kWh electricity a year will incur an additional cost of NOK 245 (including VAT) a year.

When the quota curve is at its peak in 2020, the same family will have to pay for electricity certificates for 18,3% of their electricity consumption. With unchanged consumption and a certificate price of NOK 200, the additional costs will amount to NOK 915 (including VAT)[28].

4. Trondheim smart city

Norway as a nation can save 20% of its energy consumption by using existing energy efficient technology, equivalent to the consumption of half the number of Norwegian households. The same applies to Trondheim. By utilizing energy efficient technology, Trondheim can reduce its stationary energy consumption by 22% [30]. Large quantities of energy can be saved by using existing technology available today, and the energy efficiency improvements can be achieved without affecting citizens' lifestyles or living standards. Table 2 shows how much of the city's stationary energy consumption can be released based on a study conducted by Siemens, Bellona and Trondheim Kommune. As shown below, the overall potential for energy efficiency in homes and other private and public sector buildings in Trondheim municipality totals 765 GWh, which is the equivalent of the amount of energy used by Trondheim's hotels and restaurants over 14 years or Trondheim's nurseries, schools and universities combined energy use for the next two and a half years. Households have the most potential in energy saving [30].

Table 2 Possible release of the city's stationary energy consumption [30]

Area	GWh
Residential buildings	387
Commercial buildings	378
Industry	52
Street lights	5
Upgrade of electricity distribution network	50
Total	**872**

There are several reasons for choosing Trondheim. In Norway the city is known as the country's technology capital and is home to key education and research centers within environmentally friendly solutions, such as the Norwegian University of Science and Technology (NTNU) and SINTEF. SINTEF and NTNU probably have the largest number of researchers, laboratories and students in Scandinavia working on renewable energy. They work within education, pure research and applied research and development in close collaboration with the industry. Their industrial partners comprise both national and international energy providers, producers and energy companies. Enova, a governmental enterprise owned by the Norwegian Ministry of Petroleum and Energy set up to promote an environmentally friendly restructuring of energy use and energy production in Norway, is based in Trondheim. Trondheim also has a high level of urbanization compared to other cities in Norway, which is pivotal in being able to utilize energy efficient technology.

Trondheim is Norway’s third largest city with around 169.000 inhabitants and the city’s per capita energy consumption is 13% lower than the national average. Most other cities will therefore be able to achieve greater savings than Trondheim [30].

The total energy use within the borders of the municipality is around 5 TWh, which equals around 2% of Norway’s overall energy consumption. Energy consumption for purposes other than transport (stationary consumption) is 4 TWh. Of this, the consumption of electricity accounts for 2,5 TWh a year. If the stationary energy use for households in Trondheim is distributed between each inhabitant, the consumption is 8.100 kWh a year (2008), compared with the national average of around 9.300 kWh (2007) [30]. It is due to the fact that higher urbanization rate implies more inhabitants living in apartments compared to the rest of the Norway.

Since household sector has a highest potential for energy efficiency savings it was interesting to examine whether it is economically feasible to go one step further and to implement a smart household (a detached house and an apartment) in today’s market conditions.

4.1. Norwegian household consumption

As it has already been mentioned, buildings account for around 40% of the world’s energy consumption, with 67% of it deriving from private homes. Put differently, private homes account for 29% of the world’s overall energy consumption, and 21% of greenhouse gas emissions. The percentage is approximately the same in Norway, where households account for 30% of Norway’s stationary energy consumption. Although household energy consumption has been stable in recent years, there is substantial potential for reducing this energy consumption [30].

Table 3 shows absolute annual electricity end-use for various types of Norwegian households (farm houses, single family houses, row houses and apartments).

Table 3 Electricity end-use per household type (kWh/year) [31]

	Space heating	Hot water	Lightning	Other	Total
Farm houses	7 900	4 600	2 300	4 700	19 500
Single family house	8 300	4 700	2 200	4 400	19 600
Row house	6 000	3 600	1 600	3 500	14 700
Appartments	3 800	2 600	1 000	2 600	10 000
Total	6 700	4 000	1 800	3 800	16 300
Total share	41 %	24 %	11 %	24 %	100 %

Different dwelling and household types have different energy consumption volumes. Naturally, households in apartments use much less energy than those in detached houses and farm houses. This is related to the fact that more people are generally living there and that they have a larger dwelling area. In addition, there are more outer walls in detached houses than in apartments and, therefore, more energy loss than in apartments, which are surrounded by other apartments.

Out of these figures, economical analysis conducted in this paper uses data for a single family house (or detached house) and an apartment.

Electricity end-use breakdown for an average Norwegian household is shown on Figure 12. Space heating (if it is electricity-based) and hot water amount to about 80% of the electricity consumption. Next up is lighting with 6% and cooling with 5%. Cooking and washing together use about 5% as well as various electronic devices like PC or TV.

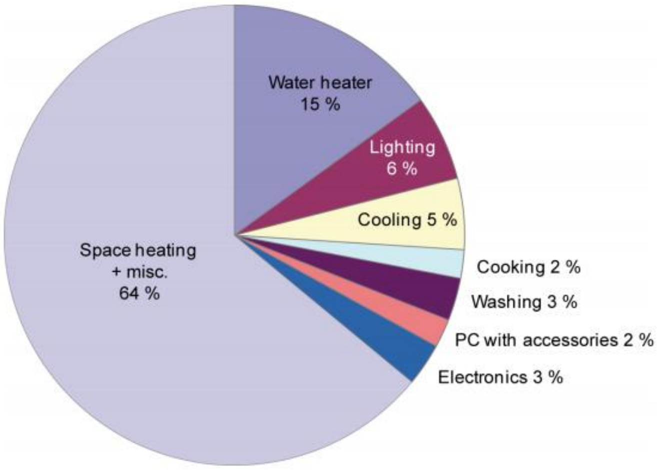


Figure 12 Percent shares of electrical end-use in Norwegian household[31]

If electricity used for heating in Norwegian households is compared internationally, it can be concluded that they are among those who use most electricity for heating. District heating is much more common in other Nordic countries. Energy efficiency potential is nested in the fact that space heating takes up most of the household electricity end-use, and can be reduced by improving building envelope. One of the measures already taken for achieving better energy efficiency was implementation of heat pumps.

4.1.1.Heat pump implementation results

Heat pump is a mechanical-compression cycle refrigeration system that can be reversed to either heat or cool a controlled space. Installation for this type of system typically consists of two parts: an indoor unit called an air handler and an outdoor unit similar to a central air conditioner, but referred to as a heat pump. A compressor circulates refrigerant that absorbs and releases heat as it travels between the indoor and outdoor units.

One of the advantages of a heat pump over a standard heating ventilating and air conditioning (HVAC) unit is that there's no need to install separate systems to heat and cool space. Heat pumps also work extremely efficiently, because they simply transfer heat, rather than burn fuel to create it. This also makes them greener than a gas-burning furnace[32].

In Norway, in 2009, heat pump was installed in 18,5% of all households. This share was as high as 33% for detached dwellings. For comparison, only 8% of households had a heat pump in 2006 and 4% in 2004.Large rise in electricity prices, especially after 2000, was probably the main reason why heat pumps have become more popular. Historically, Norwegians have been used to some of the lowest electricity prices in Europe. On the contrary, in the years of 2008-2010, they paid between 80 øre and NOK 1 per kWh. This is about the same price for electricity as in other European countries. But, as the results have shown, vast heat pump implementation in Norwegian households hasn't led to great reduction of electricity consumption, as expected [33].

Change in temperature corrected electricity consumption after installation of a heat pump is shown on Figure 13 (positive number indicates electricity consumption decrease). It has been analyzed on a sample of 164 households, measured as a difference in electricity consumption the year before and after the installation. The increase of electricity consumption has occurred for 66 households, while 98 of them have decreased it. Average annual energy saving was 1.018 kWh. That is quite modest, as some of the households achieved a lot of savings, while others increased their consumption.

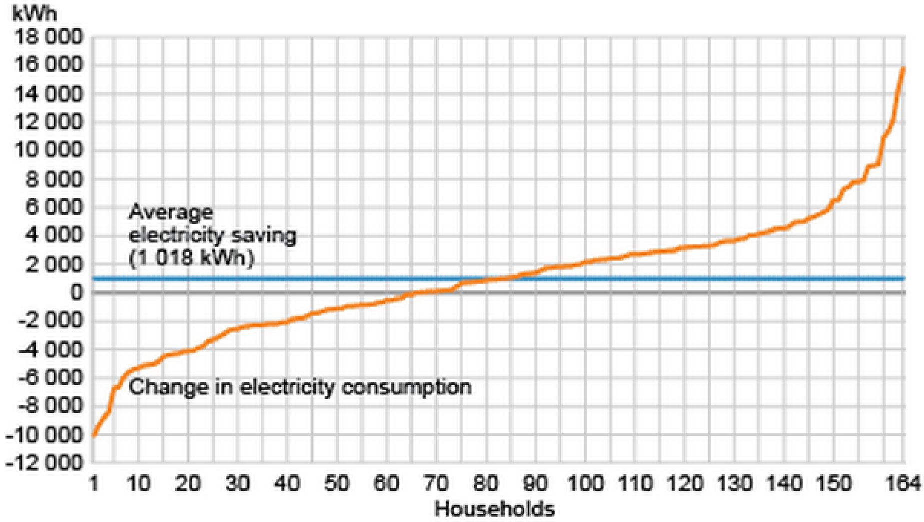


Figure 13 Change in temperature corrected electricity consumption after installation of a heat pump [33]

There are various reasons for increase in the electricity consumption connected with the installation of heat pumps. First, and the primary reason is that consumption of firewood or oil is reduced. This is no surprise as heat pumps are more practical and cheaper option in the long run. Around 60% of households use less firewood than earlier, and 7% of them use less oil. In 2009, total energy consumption in households with a heat pump was about 11-12% lower for dwellings above 150 m² (15% lower energy consumption per square meter of dwelling area in general). Electricity consumption stayed about the same, so the difference is mainly due to lower consumption of firewood and oil.

Total energy saving is also influenced by changes in behavior. In about 25% of cases, room temperature was increased, while in 33% of cases more rooms than before were heated. As for cooling in the summertime, heat pumps were used in about 25% of cases. These results indicate that comfort level was increased with implementation of the heat pumps. Also, cheaper electricity trend will probably contribute to this rise in comfort level [33].

4.1.2. District heating

Another alternative for space heating is district heating. It is a system with considerable distance between the place where heat is generated and used. It is made out of 3 parts [34]:

- A power plant as the main generation system;

- underground pipes as the distribution system; and
- Individual heating system at the user's endpoint.

From the power plant, the heat is sent through transmission piping to heat exchanger substations. The heat is traditionally distributed between the power plant and the heat exchanger substation at a flow temperature of up to 120°C. In the heat exchanger substation, it is usually exchanged down to around 90°C. The heat is then transferred through the distribution system (pipes) to the users. Principle of district heating is shown on Figure 14.

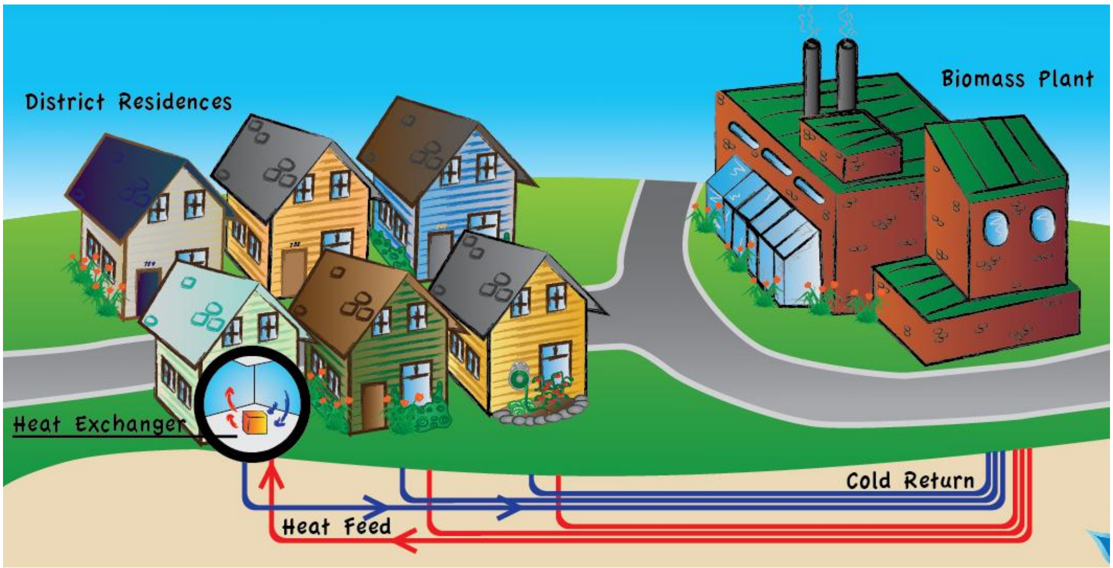


Figure 14Principle of district heating[35]

District heating plants are usually combined heat and power plants. They can be fueled by various energy sources such as biomass, solar energy and waste. Due to controlled and optimized heat generation, they are much more environmentally friendly than the individual heating systems. Furthermore, simultaneous production of heat and electricity makes them also more energy efficient. Also, they reduce the need for electric water heaters, since the supply water transfers its heat to domestic hot water through the heat exchangers.

On the other hand, relatively high heat losses caused by the long distance distribution system are one of this system's drawbacks.

District heating started in Trondheim in 1982 and district cooling in 2000. Trondheim Energi Fjernvarme AS supplies heat energy to approximately 6000 residential units and 550 business customers in the region, covering over 30% of the heating needs in

Trondheim. Out of annual 600 GWh production, 70-80% is generated through waste management[30]. Trondheim Energi Fjernvarme AS distribution map is shown on Figure 15.

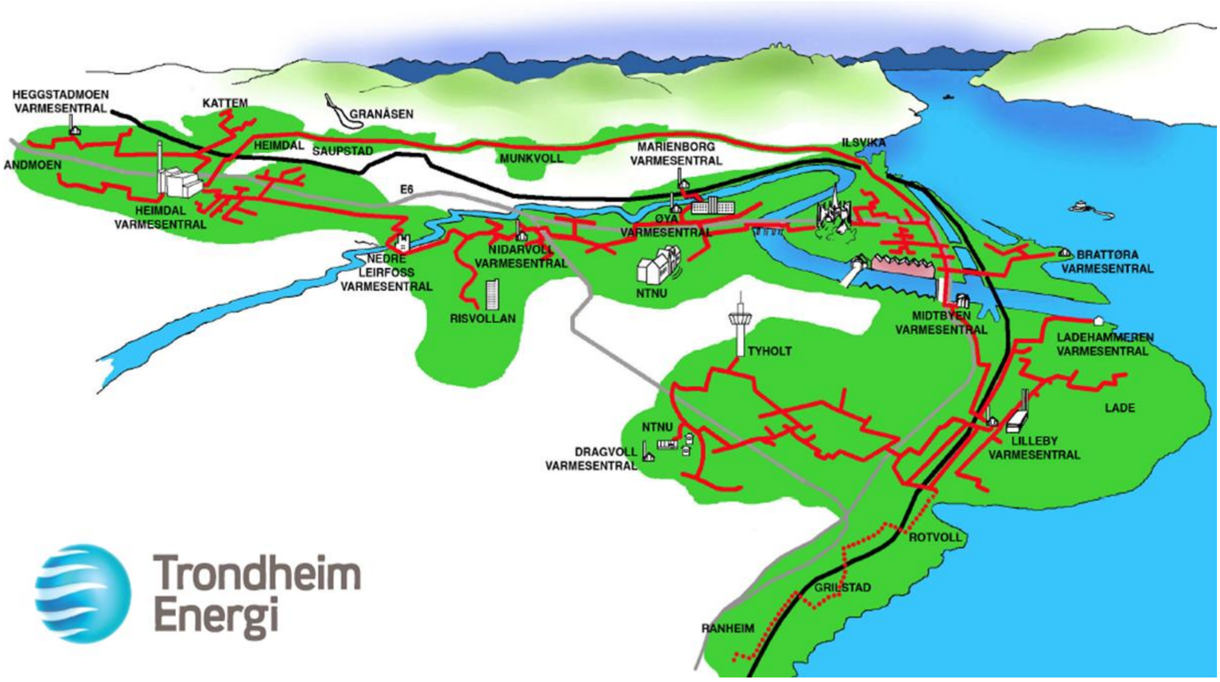


Figure 15 Trondheim Energi Fjernvarme AS distribution map [36]

District heating energy price is based on the customers alternative energy price which normally is the price for electric power and/or oil. The district heating concessions limit the district heating energy price to the price for electric power in the same area[37].

4.2. Dwellings in Trondheim

To implement a smart household in Trondheim with PV modules as an on-site renewable energy source it was important to assess how many PV modules in average one can fit on Trondheim’s typical detached house and apartment. That is why average rooftop area has been calculated in both cases.

Data taken from Statistics Norway (from year 2011) represent dwellings-breakdown in Trondheim municipality by dwelling type and utility floor size. These data are shown in Table 4.

Table 4 Dwellings, by type of building and utility floor space [38]

Square meters	Detached house	House with 2 dwellings	Row house	Multi-dwelling building
less than 30	436	148	206	1.703
30-39	275	75	211	2.820
40-49	467	116	306	3.949
50-59	793	190	703	5.142
60-79	1.268	774	2.579	11.142
80-99	1.556	1.906	2.707	6.824
100-119	2.003	1.831	2.878	1.956
120-139	2.260	1.907	1.812	594
140-159	2.120	1.364	1.909	317
160-199	4.280	1.412	1.153	256
200-249	3.144	489	276	85
250-299	1.360	141	48	10
300-349	368	46	15	8
350 or more	215	28	4	8
Total	20.545	10.427	14.807	34.814

Table 5 shows number of dwellings in Trondheim municipality by position (floor) in the building.

Table 5 Dwellings, by position (floor) in the building [38]

Position	Number of dwellings
Basement	320
Lower ground floor	5.043
First floor	48.637
Second floor	17.902
Third floor	9.133

Fourth floor	4.614
Fifth floor or higher	3.584
Attic	440

Average rooftop area was calculated using data provided for detached houses and apartments in row houses and multi-dwelling buildings.

Assuming that houses with area of 100 m² and greater have two floors average rooftop area for detached house is 82,4 m².

When calculating rooftop area for an apartment it was necessary to calculate average apartment floor area and divide it by the average number of floors in row house/multi-dwelling building. From the data provided in Table 5 it was calculated that the average number of floors in such buildings is three. Since the average apartment floor size is 68,64 m², that gives us an average apartment rooftop area of 22,88 m².

Chosen PV panels are REC 250PE with 25 year linear power output warranty (max. degression in performance of 0,7%) and panel area of 1,65 m². This panel longevity is the parameter that defines project's life cycle[39].

For detached houses, it was chosen to install three PV arrays each containing 13 panels. That gives us total of 39 panels which means that 78% of the rooftop area is covered. Security margin of 22% is provided so that optimal panel orientation mounting doesn't create much shading.

For an apartment, it was chosen to install one PV array containing 10 panels. In this case security margin is as high as 28% because row houses/multi-dwelling buildings mostly have horizontal rooftops. In that case optimal panel orientation mounting creates even greater shading.

5. Smart households in Trondheim

This paper examines fifteen cases of turning Norwegian and Croatian households into smart ones (Figure 16). Those are various combinations of consumption, generation and storage options. In order to show expenses and revenues, well as profitability of such projects, cost and benefit analysis has been conducted.

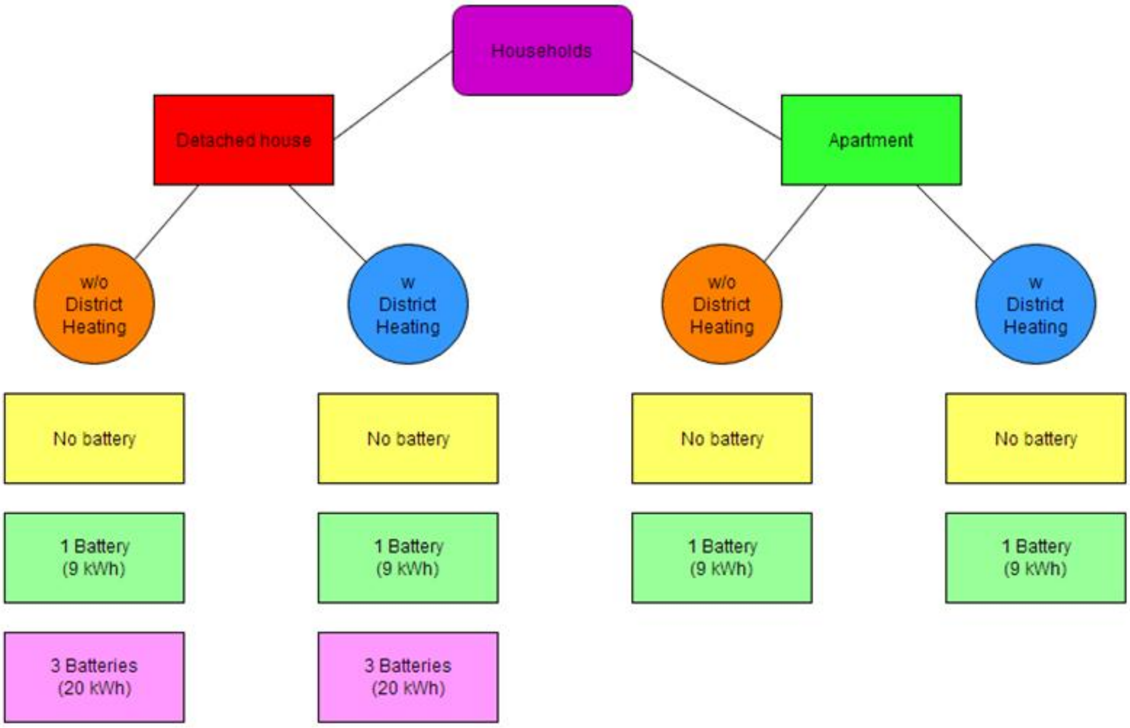


Figure 16 Households consumption and storage variations

Each household has been equipped with a PV generation system (panels and inverters), smart meter, energy management system and, in some cases, energy storage system.

Smart household gains revenues from selling some of the generated electricity to the grid and from savings due to self-consumption. Those equipped with energy storage system sell less and use more of the electricity produced on their own.

SMA Sunny Design software has been used to calculate yearly production, amount of electricity sold to the grid and self-consumption. The rest is being bought from a local supplier. It also provided information about annual battery life cycles which is important when assessing the durability of the battery.

As it has already been mentioned, Trondheim's households have been investigated in terms of electricity consumption, space heating options and average utility floor space.

But before further analysis, electricity price prediction has to be addressed.

5.1. Electricity price prediction

When conducting cost and benefit analysis, besides yearly energy yields and cost of equipment installed, it was necessary to predict market electricity price which determines yearly revenues of selling PV produced electricity to the grid.

Since project's life cycle is 25 years this prediction was calculated for the period of 2015 to 2039 based on average annual Elspot prices from 2003 to 2013 for Trondheim area (Table 6)[40]. Based on the data provided, equation for the linear trendline has been made Figure 17) and then extrapolated until year 2039.

Table 6 Historical data of average annual Elspot prices for Trondheim area

Year	€/MWh
2013	38,96
2012	31,48
2011	47,49
2010	58,04
2009	35,55
2008	51,17
2007	29,59
2006	48,97
2005	29,39
2004	29,12
2003	36,66

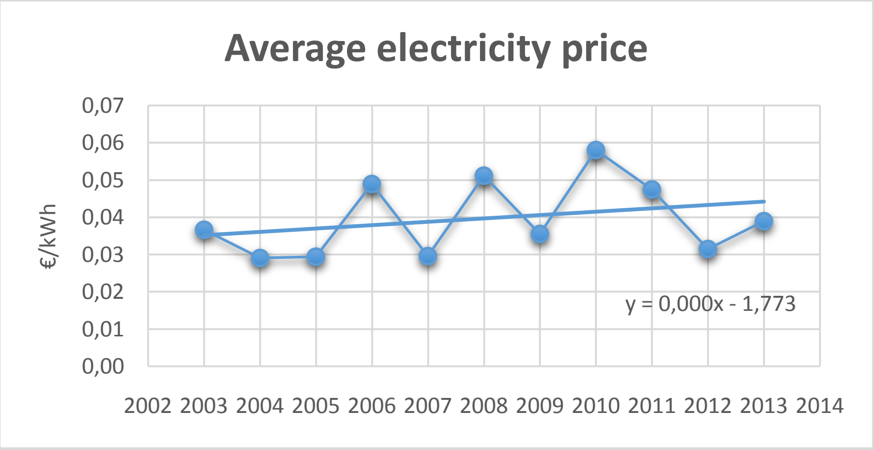


Figure 17 Linear trendline for Trondheim area Elspot prices

To that spot price average green certificate price has been added, which was calculated based on historical data (Figure 18) [41]. Monthly figures have been analyzed since green certificate market operates only since January 2012. As it is visible on Figure 18, green certificate price hasn't been fluctuating all that much, so for the purpose of this analysis average price of 21,18 €/MWh has been taken into account.

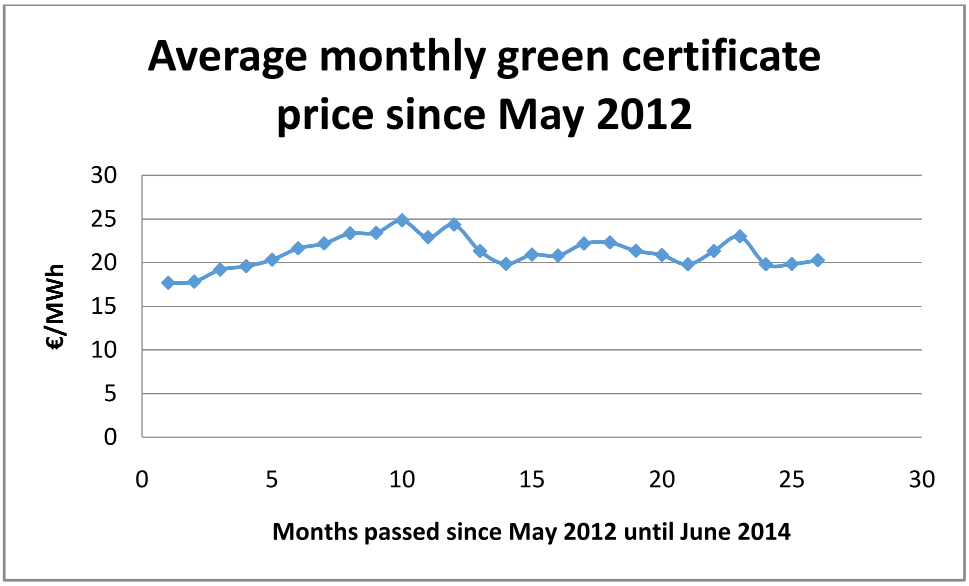


Figure 18 Average monthly green certificate price since May 2012

The same price increase trend as for the spot price was then applied to today's household tariff of 0,05227 €/kWh [42] extrapolated by the *y = 0,0009x - 1,7737* equation where x-axis represents current year and y-axis is the according tariff price in €/kWh (Figure 19).

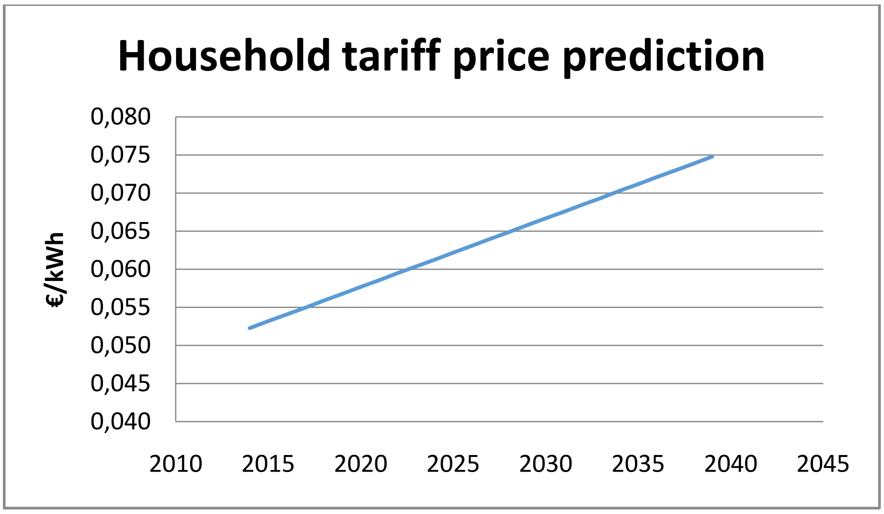


Figure 19 Household tariff price prediction

This is important for calculating savings from self-consumption as well as costs for buying additional electricity needed.

5.2. Apartment without district heating

An apartment without district heating has a yearly electricity consumption of 10.000 kWh.

Average daily profile of electricity consumption by season is shown on Figure 20 (source: SMA Sunny Design) for private household with typical load peaks at lunchtime and further consumption increases in the morning and evening.

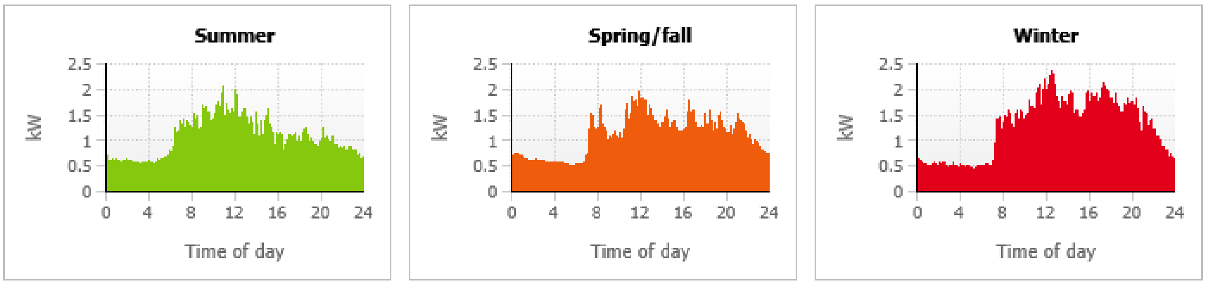


Figure 20Average daily profile of electricity consumption for an apartment without district heating in Trondheim

5.2.1. Apartment without district heating without energy storage

REC Peak Energy Series panels are the perfect choice for building solar systems that combine long lasting product quality with reliable power output [43]. In this case 10 of the REC 250PE solar panels are installed in one PV array with SMA SB 2100 TL inverter [44].

The smart meter monitors power imported from the grid, as well as power exported from the solar panels. In this way, it is possible to keep track of all energy data, ensuring accuracy in billing and crediting. The chosen meter is SMA Energy Meter [45].

The Sunny Home Manager [46] serves as control center and key component in the smart home. Combined with a PV inverter, the Sunny Home Manager guarantees not only comprehensive monitoring but also analysis and visualization of all relevant energy flows in the home. In addition, it also forecasts and plans PV generation as well as consumption and controls the loads as a whole. It is the energy management system that enables [47]:

- Self-consumption optimization;
- Analysis of consumption and management of loads; and
- Plant monitoring on the internet and visualization of plant data.

Except for equipment costs, there are other expenses that have to be taken into consideration when installing renewable resources such as photovoltaic: studies and elaborations of impact to the grid, fee for grid connection, and other specific costs such as communication upgrades and wired infrastructure [48].

Besides that, there is also additional cost for 2,5 mm² copper cables (DC before and AC after inverter as shown on Figure 21) [49].

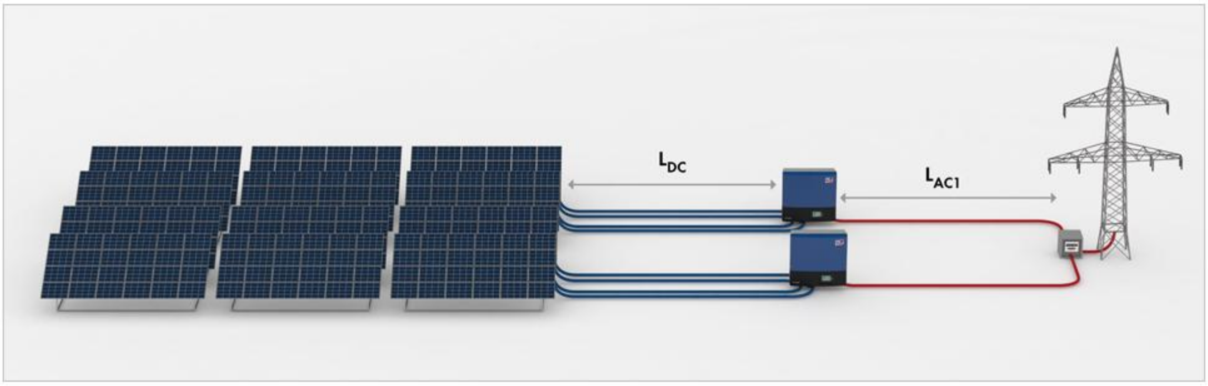


Figure 21 Copper cables scheme (source: SMA Sunny Design)

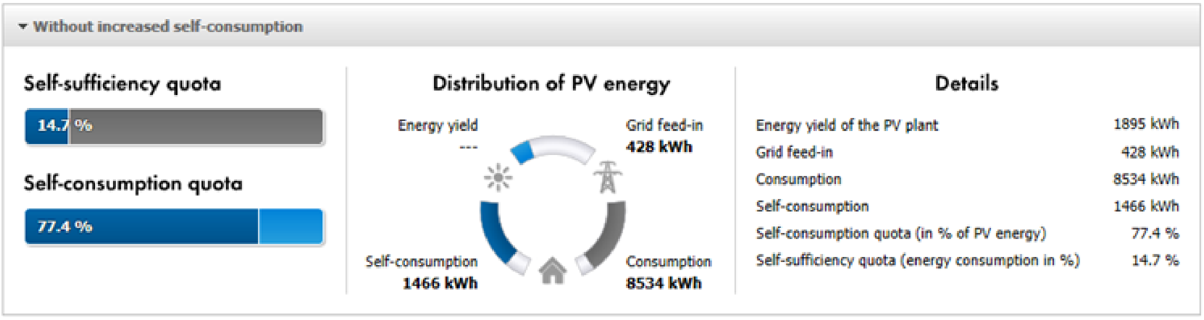
Equipment installed in this case is listed in the Table 7.

Table 7Initial costs for an apartment without energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	10	1.936,60
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.600,00	1	1.600,00
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	30	70,50
TOTAL			7.102,33

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 22.

Out of 1895 kWh yielded from the PV system, 428 kWh were fed into the grid. The rest (1466 kWh) is direct self-consumption since this case hasn’t got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (8534 kWh), and yearly operational costs which are calculated as 1% of initial costs.


▾ Without increased self-consumption

Self-sufficiency quota

14.7 %

Self-consumption quota

77.4 %

Distribution of PV energy

Energy yield

Grid feed-in
428 kWh

Self-consumption
1466 kWh

Consumption
8534 kWh

Details

Energy yield of the PV plant	1895 kWh
Grid feed-in	428 kWh
Consumption	8534 kWh
Self-consumption	1466 kWh
Self-consumption quota (in % of PV energy)	77.4 %
Self-sufficiency quota (energy consumption in %)	14.7 %

Figure 22Energy yield of an apartment without district heating without energy storage

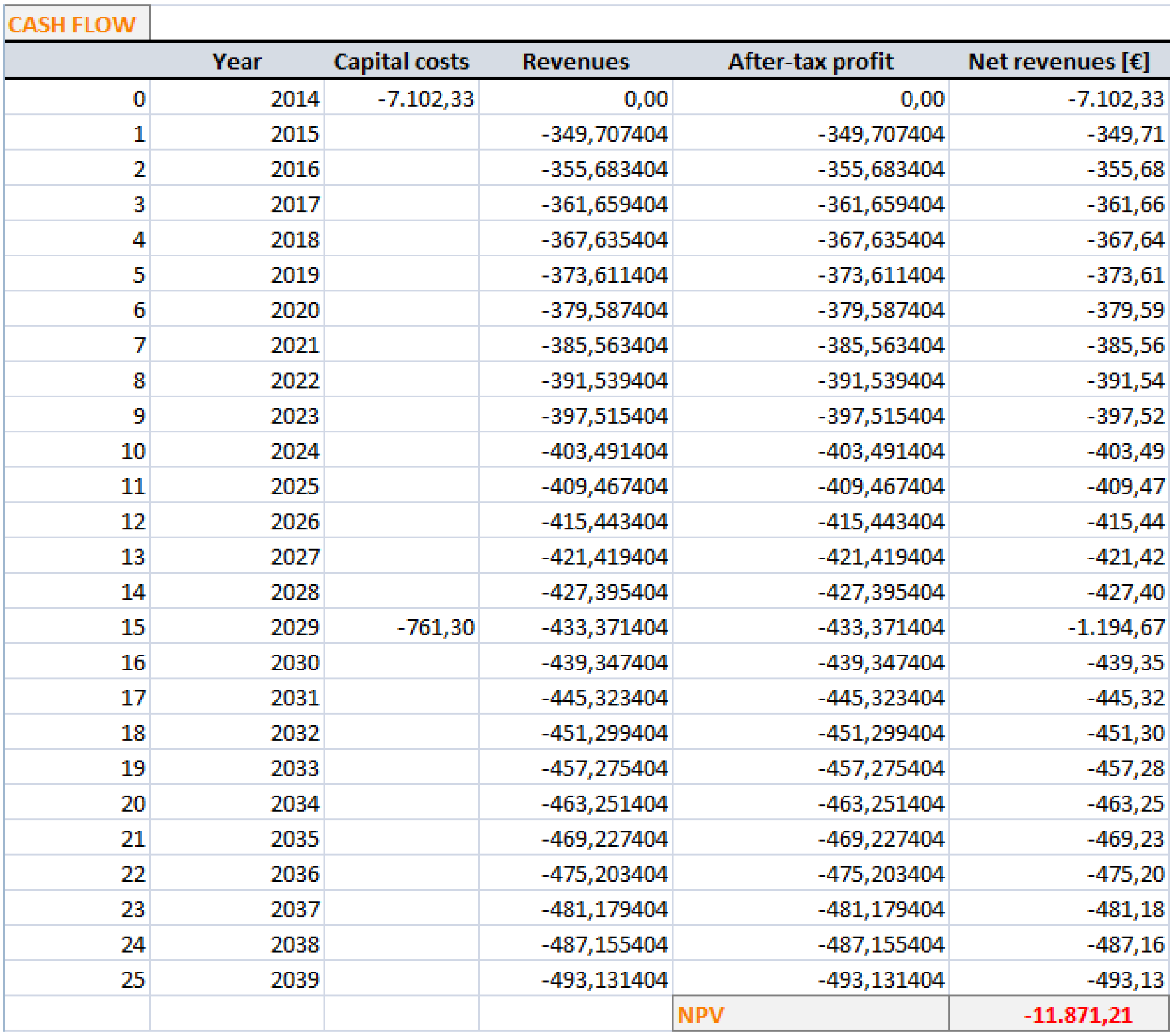
After defining initial costs, energy yields and additional consumption, economic cash flow was conducted in order to estimate the profitability of installing described smart household (Table 8).

Additional capital cost in year 2029 represents inverter change. After calculating revenues they must be taxed with a 28% rate of Norwegian income tax [50]. Since none of the yearly revenues were positive, this wasn't applied in this case.

Discount rate for calculating net present value of 7% has been taken into account [51].

Net present value was calculated from the economic cash flow and it was obtained that it is negative. This means that it is not profitable to implement a smart apartment without district heating without energy storage in today's environment in Trondheim.

Table 8Economic cash flow for an apartment without district heating without energy storage



CASH FLOW

	Year	Capital costs	Revenues	After-tax profit	Net revenues [€]
0	2014	-7.102,33	0,00	0,00	-7.102,33
1	2015		-349,707404	-349,707404	-349,71
2	2016		-355,683404	-355,683404	-355,68
3	2017		-361,659404	-361,659404	-361,66
4	2018		-367,635404	-367,635404	-367,64
5	2019		-373,611404	-373,611404	-373,61
6	2020		-379,587404	-379,587404	-379,59
7	2021		-385,563404	-385,563404	-385,56
8	2022		-391,539404	-391,539404	-391,54
9	2023		-397,515404	-397,515404	-397,52
10	2024		-403,491404	-403,491404	-403,49
11	2025		-409,467404	-409,467404	-409,47
12	2026		-415,443404	-415,443404	-415,44
13	2027		-421,419404	-421,419404	-421,42
14	2028		-427,395404	-427,395404	-427,40
15	2029	-761,30	-433,371404	-433,371404	-1.194,67
16	2030		-439,347404	-439,347404	-439,35
17	2031		-445,323404	-445,323404	-445,32
18	2032		-451,299404	-451,299404	-451,30
19	2033		-457,275404	-457,275404	-457,28
20	2034		-463,251404	-463,251404	-463,25
21	2035		-469,227404	-469,227404	-469,23
22	2036		-475,203404	-475,203404	-475,20
23	2037		-481,179404	-481,179404	-481,18
24	2038		-487,155404	-487,155404	-487,16
25	2039		-493,131404	-493,131404	-493,13
				NPV	-11.871,21

5.2.2. Apartment without district heating with 9 kWh energy storage

In this case, initial costs are the same as for the apartment without district heating without energy storage, with added cost of energy storage system.

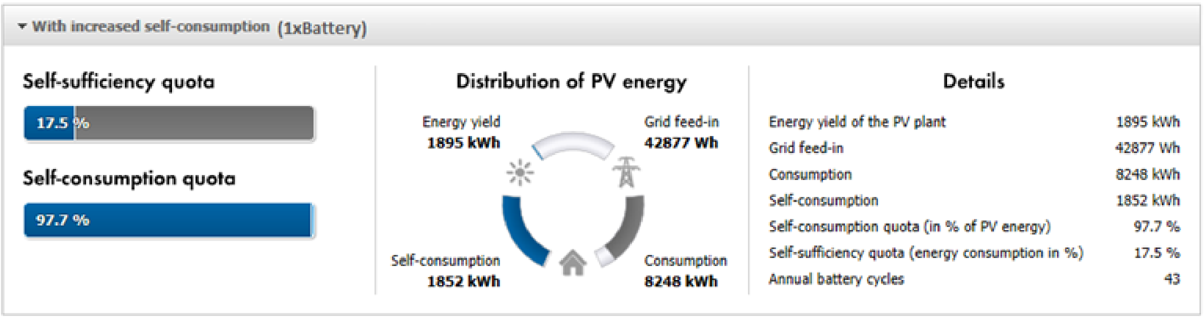
Chosen battery is SMA Sunny Island 6.0H which provides 9 kWh energy storage capacity[52]. Due to their high charge and discharge load, Hoppecke's sealed lead-gel batteries are optimally suitable for solar power storage. Thanks to the gel technology, they have a cycle life of about 2500 cycles with a 50% depth of discharge[53].

Equipment installed in this case is listed in the Table 9.

Table 9 Initial costs for an apartment with 9 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	10	1.936,60
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.600,00	1	1.600,00
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	30	70,50
Battery SMA Sunny Island	2.517,37	1	2.517,37
TOTAL			9.619,70

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 23.


▾ With increased self-consumption (1xBattery)

Self-sufficiency quota

17.5 %

Self-consumption quota

97.7 %

Distribution of PV energy

Details

Energy yield of the PV plant	1895 kWh
Grid feed-in	42877 Wh
Consumption	8248 kWh
Self-consumption	1852 kWh
Self-consumption quota (in % of PV energy)	97.7 %
Self-sufficiency quota (energy consumption in %)	17.5 %
Annual battery cycles	43

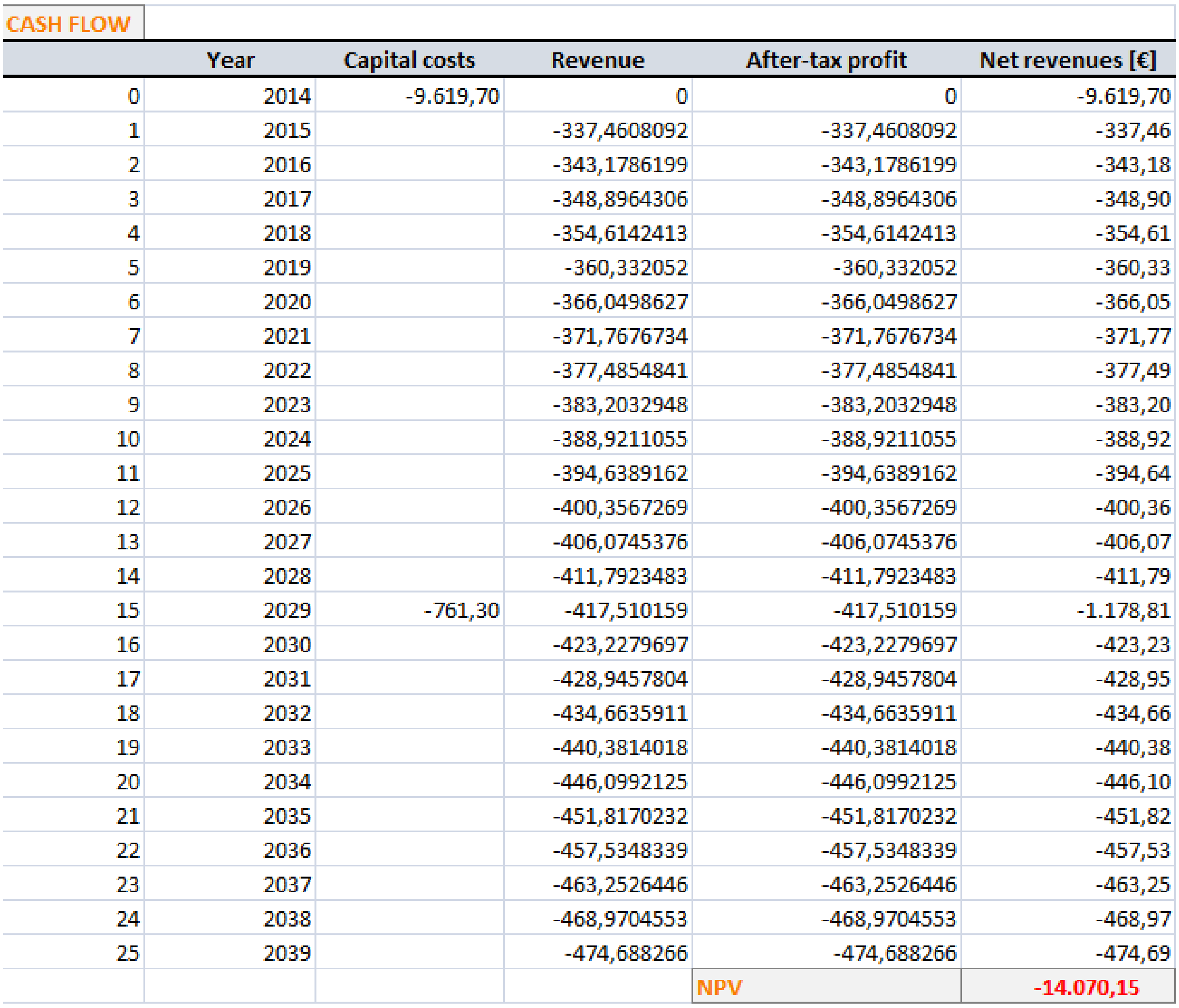
Figure 23Energy yield of an apartment without district heating with 9 kWh energy storage

Out of 1895 kWh yielded from the PV system, 42,877 kWh were fed into the grid. The rest (1852 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (8248 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 10. In this case battery had 43 annual life cycles which means it doesn’t have to be replaced within project’s life cycle of 25 years.

Net present value was calculated from the economic cash flow and turned out to be negative. This means that it is not profitable to implement a smart apartment without district heating with 9 kWh energy storage in today’s environment in Trondheim.

Table 10Economic cash flow for an apartment without district heating with 9 kWh energy storage



CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-9.619,70	0	0	-9.619,70
1	2015		-337,4608092	-337,4608092	-337,46
2	2016		-343,1786199	-343,1786199	-343,18
3	2017		-348,8964306	-348,8964306	-348,90
4	2018		-354,6142413	-354,6142413	-354,61
5	2019		-360,332052	-360,332052	-360,33
6	2020		-366,0498627	-366,0498627	-366,05
7	2021		-371,7676734	-371,7676734	-371,77
8	2022		-377,4854841	-377,4854841	-377,49
9	2023		-383,2032948	-383,2032948	-383,20
10	2024		-388,9211055	-388,9211055	-388,92
11	2025		-394,6389162	-394,6389162	-394,64
12	2026		-400,3567269	-400,3567269	-400,36
13	2027		-406,0745376	-406,0745376	-406,07
14	2028		-411,7923483	-411,7923483	-411,79
15	2029	-761,30	-417,510159	-417,510159	-1.178,81
16	2030		-423,2279697	-423,2279697	-423,23
17	2031		-428,9457804	-428,9457804	-428,95
18	2032		-434,6635911	-434,6635911	-434,66
19	2033		-440,3814018	-440,3814018	-440,38
20	2034		-446,0992125	-446,0992125	-446,10
21	2035		-451,8170232	-451,8170232	-451,82
22	2036		-457,5348339	-457,5348339	-457,53
23	2037		-463,2526446	-463,2526446	-463,25
24	2038		-468,9704553	-468,9704553	-468,97
25	2039		-474,688266	-474,688266	-474,69
				NPV	**-14.070,15**

5.3. Apartment with district heating

An apartment with district heating has a yearly electricity consumption of 6.200 kWh.

Average daily profile of electricity consumption by season is shown on Figure 24 (source: SMA Sunny Design).

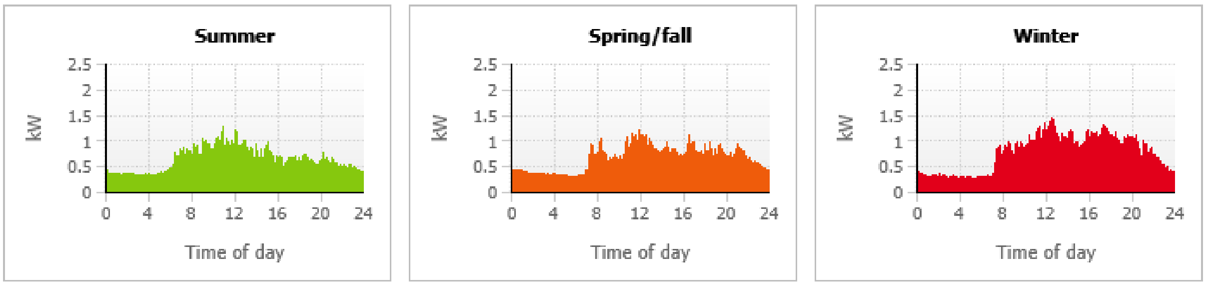
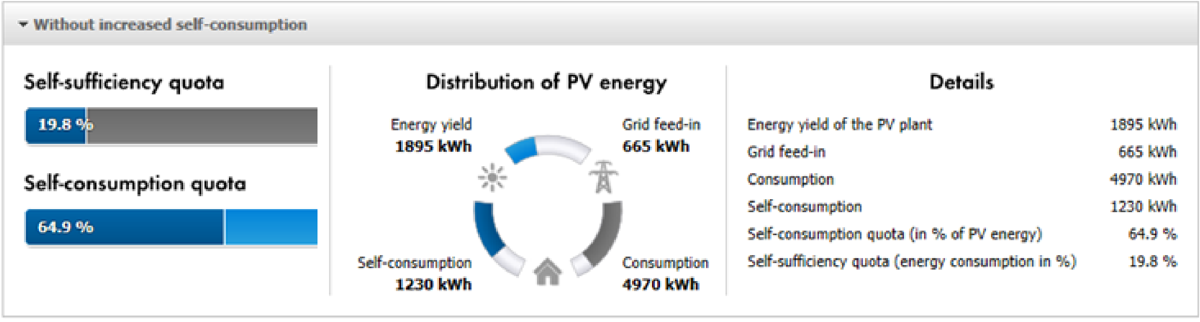


Figure 24Average daily profile of electricity consumption for an apartment with district heating in Trondheim

5.3.1. Apartment with district heating without energy storage

Initial costs are the same as for the case of an apartment without district heating without energy storage.

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 25.



▾ Without increased self-consumption

Self-sufficiency quota

19.8 %

Self-consumption quota

64.9 %

Distribution of PV energy

Energy yield
1895 kWh

Grid feed-in
665 kWh

Self-consumption
1230 kWh

Consumption
4970 kWh

Details

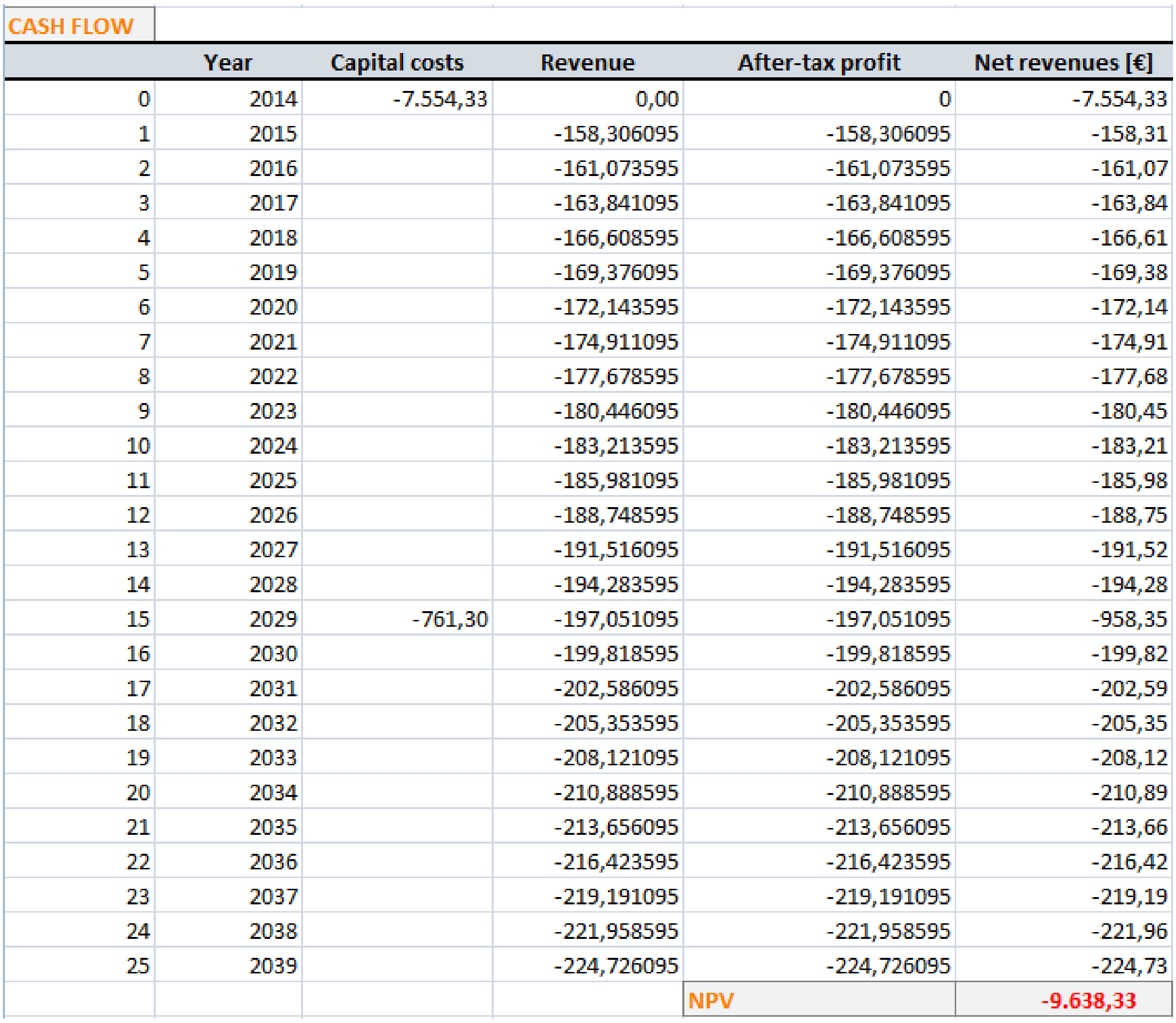
Energy yield of the PV plant	1895 kWh
Grid feed-in	665 kWh
Consumption	4970 kWh
Self-consumption	1230 kWh
Self-consumption quota (in % of PV energy)	64.9 %
Self-sufficiency quota (energy consumption in %)	19.8 %

Figure 25 Energy yield of an apartment with district heating without energy storage

Out of 1895 kWh yielded from the PV system, 665 kWh were fed into the grid. The rest (1230 kWh) is direct self-consumption since this case hasn't got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (4970 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 11.

Table 11Economic cash flow for an apartment with district heating without energy storage



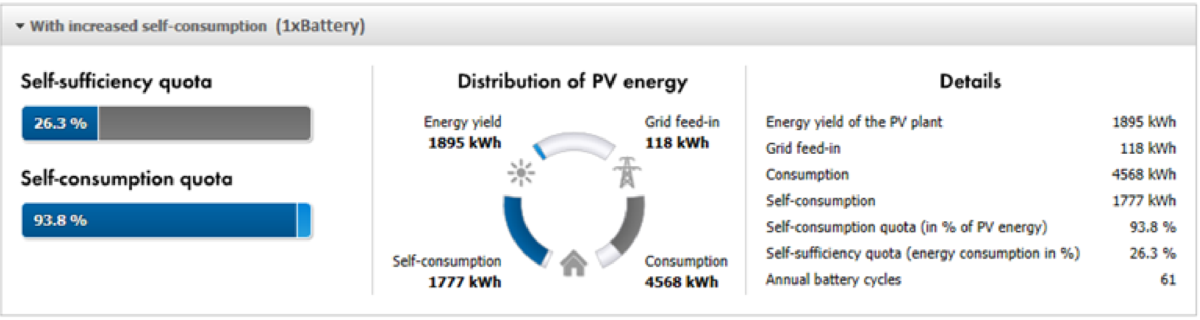
CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-7.554,33	0,00	0	-7.554,33
1	2015		-158,306095	-158,306095	-158,31
2	2016		-161,073595	-161,073595	-161,07
3	2017		-163,841095	-163,841095	-163,84
4	2018		-166,608595	-166,608595	-166,61
5	2019		-169,376095	-169,376095	-169,38
6	2020		-172,143595	-172,143595	-172,14
7	2021		-174,911095	-174,911095	-174,91
8	2022		-177,678595	-177,678595	-177,68
9	2023		-180,446095	-180,446095	-180,45
10	2024		-183,213595	-183,213595	-183,21
11	2025		-185,981095	-185,981095	-185,98
12	2026		-188,748595	-188,748595	-188,75
13	2027		-191,516095	-191,516095	-191,52
14	2028		-194,283595	-194,283595	-194,28
15	2029	-761,30	-197,051095	-197,051095	-958,35
16	2030		-199,818595	-199,818595	-199,82
17	2031		-202,586095	-202,586095	-202,59
18	2032		-205,353595	-205,353595	-205,35
19	2033		-208,121095	-208,121095	-208,12
20	2034		-210,888595	-210,888595	-210,89
21	2035		-213,656095	-213,656095	-213,66
22	2036		-216,423595	-216,423595	-216,42
23	2037		-219,191095	-219,191095	-219,19
24	2038		-221,958595	-221,958595	-221,96
25	2039		-224,726095	-224,726095	-224,73
				NPV	-9.638,33

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart apartment with district heating without energy storage in today’s environment in Trondheim.

5.3.2. Apartment with district heating with 9 kWh energy storage

Initial costs are the same as for the case of an apartment without district heating with 9 kWh energy storage.

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 26.



Self-sufficiency quota

26.3 %

Self-consumption quota

93.8 %

Details

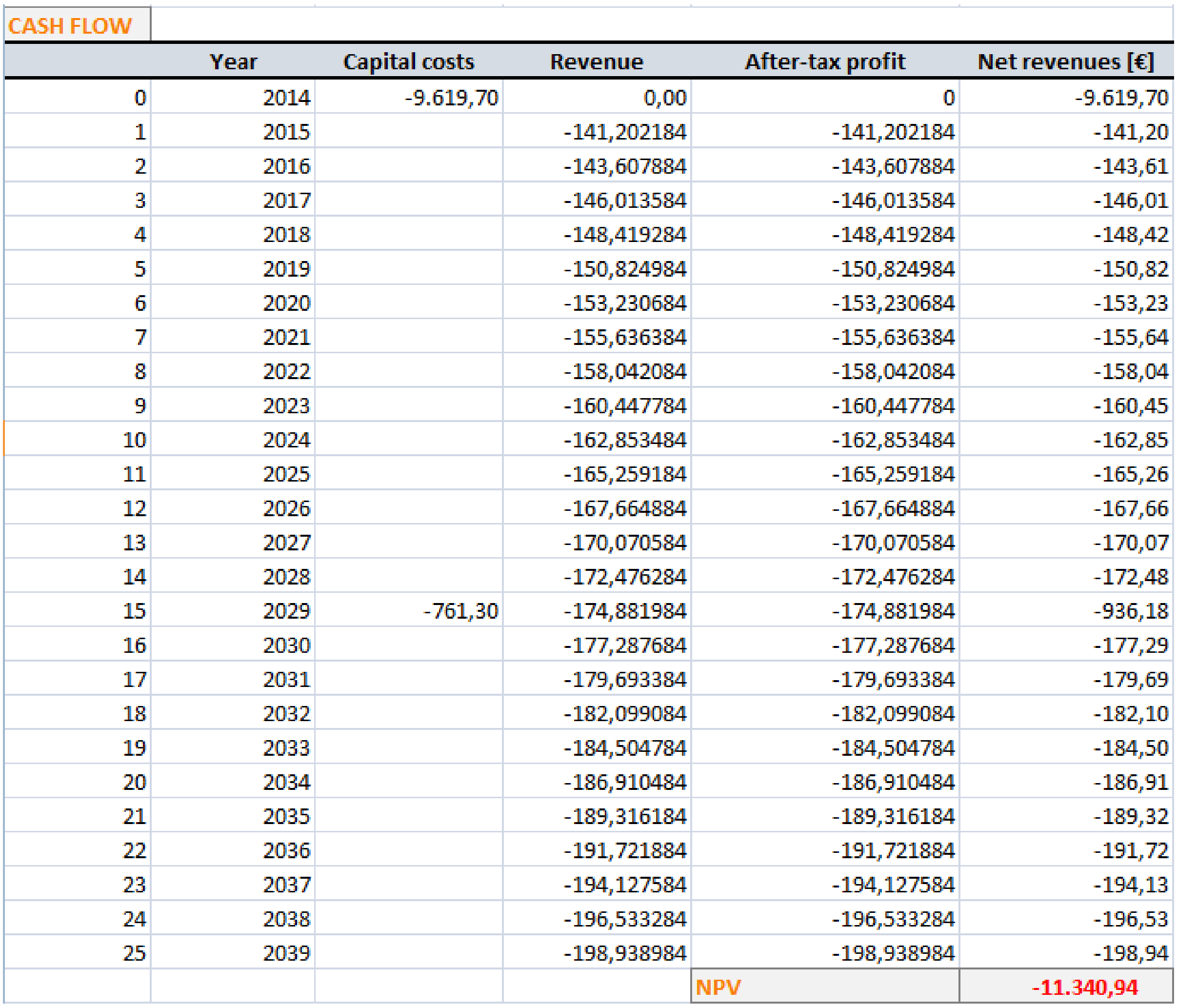
Energy yield of the PV plant	1895 kWh
Grid feed-in	118 kWh
Consumption	4568 kWh
Self-consumption	1777 kWh
Self-consumption quota (in % of PV energy)	93.8 %
Self-sufficiency quota (energy consumption in %)	26.3 %
Annual battery cycles	61

Figure 26Energy yield of an apartment with district heating with 9 kWh energy storage

Out of 1895 kWh yielded from the PV system, 118 kWh were fed into the grid. The rest (1777 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (4568 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 12.

Table 12Economic cash flow for an apartment with district heating with 9 kWh energy storage



CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-9.619,70	0,00	0	-9.619,70
1	2015		-141,202184	-141,202184	-141,20
2	2016		-143,607884	-143,607884	-143,61
3	2017		-146,013584	-146,013584	-146,01
4	2018		-148,419284	-148,419284	-148,42
5	2019		-150,824984	-150,824984	-150,82
6	2020		-153,230684	-153,230684	-153,23
7	2021		-155,636384	-155,636384	-155,64
8	2022		-158,042084	-158,042084	-158,04
9	2023		-160,447784	-160,447784	-160,45
10	2024		-162,853484	-162,853484	-162,85
11	2025		-165,259184	-165,259184	-165,26
12	2026		-167,664884	-167,664884	-167,66
13	2027		-170,070584	-170,070584	-170,07
14	2028		-172,476284	-172,476284	-172,48
15	2029	-761,30	-174,881984	-174,881984	-936,18
16	2030		-177,287684	-177,287684	-177,29
17	2031		-179,693384	-179,693384	-179,69
18	2032		-182,099084	-182,099084	-182,10
19	2033		-184,504784	-184,504784	-184,50
20	2034		-186,910484	-186,910484	-186,91
21	2035		-189,316184	-189,316184	-189,32
22	2036		-191,721884	-191,721884	-191,72
23	2037		-194,127584	-194,127584	-194,13
24	2038		-196,533284	-196,533284	-196,53
25	2039		-198,938984	-198,938984	-198,94
				NPV	-11.340,94

In this case battery had 61 annual life cycles which means it doesn't have to be replaced within project's life cycle of 25 years.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart apartment with district heating with 9 kWh energy storage in today's environment in Trondheim.

5.4. Detached house without district heating

A detached house without district heating has a yearly electricity consumption of 19.600 kWh.

Average daily profile of electricity consumption by season is shown on Figure 27 (source: SMA Sunny Design).

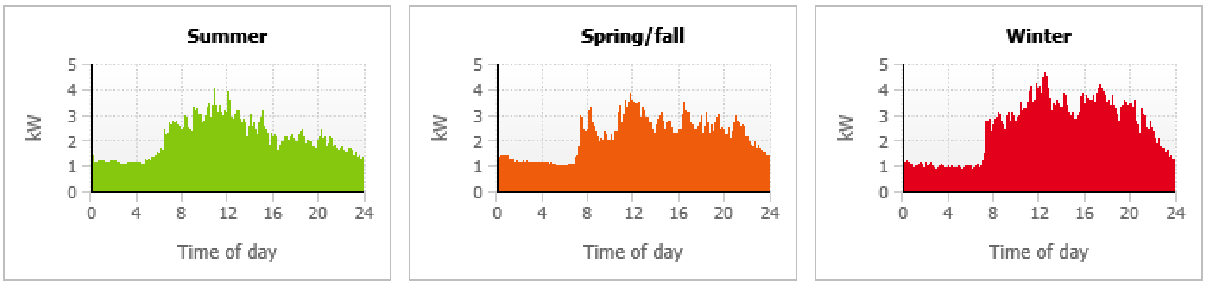


Figure 27Average daily profile of electricity consumption for a detached house without district heating in Trondheim

5.4.1. Detached house without district heating without energy storage

In this case 39 of the REC 250PE solar panels are installed in three PV arrays with two SMA SB 4000 TL-21 inverters.

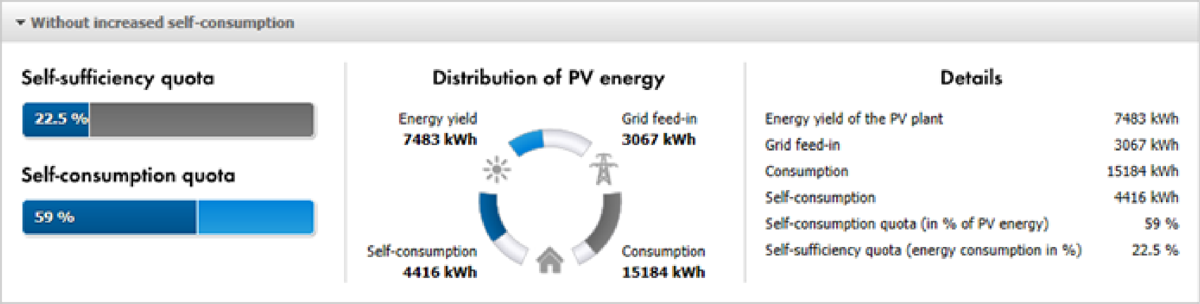
Copper cable length has been increased by 70 m and the rest of the costs are the same as for the apartment without district heating without energy storage (Table 13).

Table 13Initial costs for a detached house without energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 4000 TL-21	1.235,00	2	2.470,00
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.600,00	1	1.600,00

Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
TOTAL			14.591,67

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 28.



Without increased self-consumption

Self-sufficiency quota

22.5 %

Self-consumption quota

59 %

Distribution of PV energy

Energy yield
7483 kWh

Grid feed-in
3067 kWh

Self-consumption
4416 kWh

Consumption
15184 kWh

Details

Details	
Energy yield of the PV plant	7483 kWh
Grid feed-in	3067 kWh
Consumption	15184 kWh
Self-consumption	4416 kWh
Self-consumption quota (in % of PV energy)	59 %
Self-sufficiency quota (energy consumption in %)	22.5 %

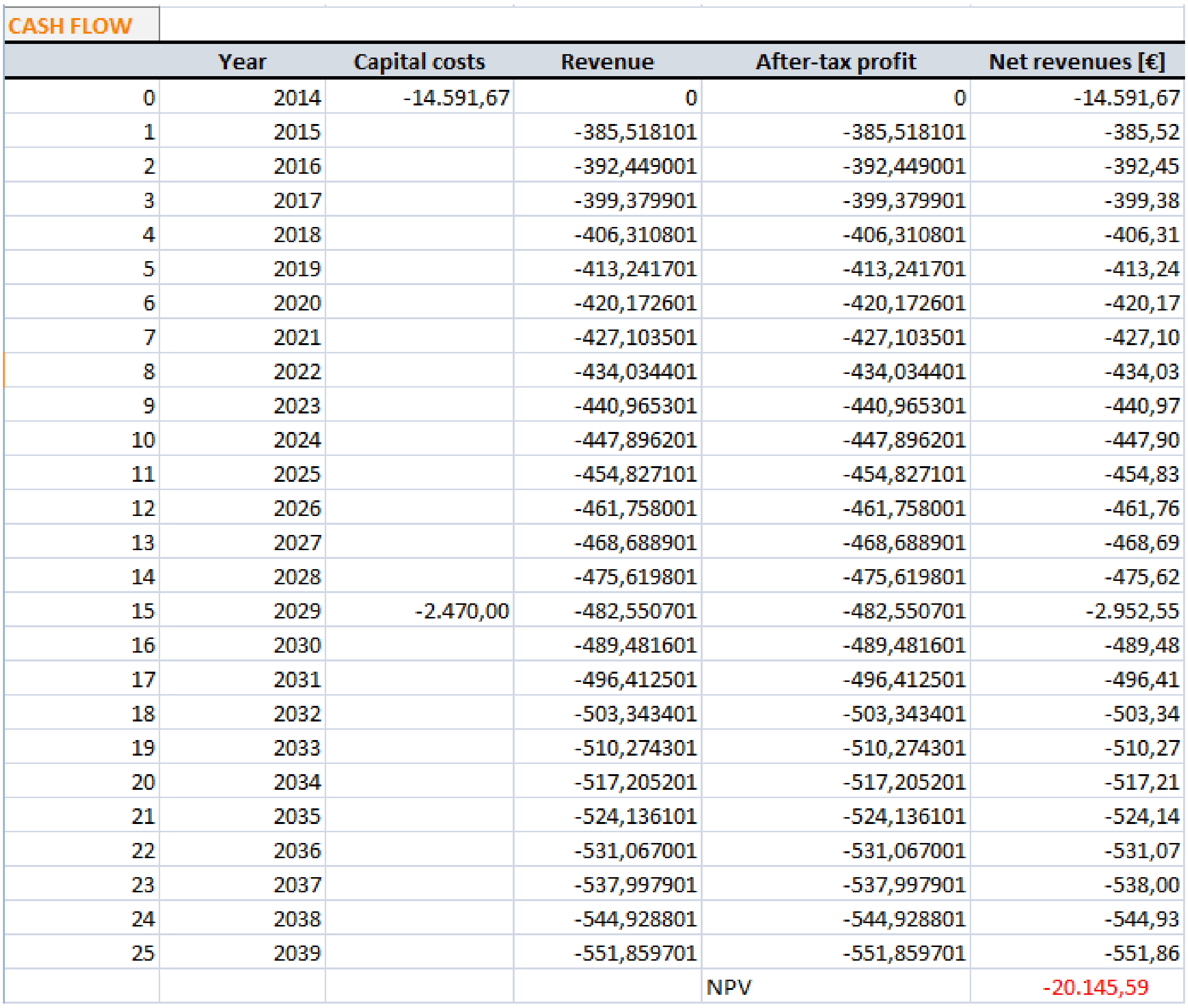
Figure 28Energy yield of a detached house without district heating without energy storage

Out of 7483 kWh yielded from the PV system, 3067 kWh were fed into the grid. The rest (4416 kWh) is direct self-consumption since this case hasn’t got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (15184 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 14.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house without district heating without energy storage in today’s environment in Trondheim.

Table 14 Economic cash flow for a detached house without district heating without energy storage



CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-14.591,67	0	0	-14.591,67
1	2015		-385,518101	-385,518101	-385,52
2	2016		-392,449001	-392,449001	-392,45
3	2017		-399,379901	-399,379901	-399,38
4	2018		-406,310801	-406,310801	-406,31
5	2019		-413,241701	-413,241701	-413,24
6	2020		-420,172601	-420,172601	-420,17
7	2021		-427,103501	-427,103501	-427,10
8	2022		-434,034401	-434,034401	-434,03
9	2023		-440,965301	-440,965301	-440,97
10	2024		-447,896201	-447,896201	-447,90
11	2025		-454,827101	-454,827101	-454,83
12	2026		-461,758001	-461,758001	-461,76
13	2027		-468,688901	-468,688901	-468,69
14	2028		-475,619801	-475,619801	-475,62
15	2029	-2.470,00	-482,550701	-482,550701	-2.952,55
16	2030		-489,481601	-489,481601	-489,48
17	2031		-496,412501	-496,412501	-496,41
18	2032		-503,343401	-503,343401	-503,34
19	2033		-510,274301	-510,274301	-510,27
20	2034		-517,205201	-517,205201	-517,21
21	2035		-524,136101	-524,136101	-524,14
22	2036		-531,067001	-531,067001	-531,07
23	2037		-537,997901	-537,997901	-538,00
24	2038		-544,928801	-544,928801	-544,93
25	2039		-551,859701	-551,859701	-551,86
				NPV	-20.145,59

5.4.2. Detached house without district heating with 9 kWh energy storage

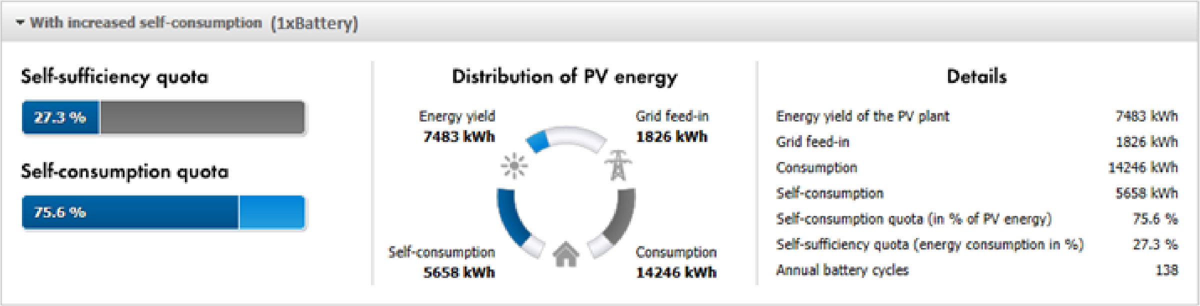
In this case, initial costs (Table 15) are the same as for the detached house without district heating without energy storage, with added cost of energy storage system (one SMA Sunny Island 6.0H battery).

Table 15 Initial costs for a detached house with 9 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 4000 TL-21	1.235,00	2	2.470,00
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93

Connection to the grid	1.600,00	1	1.600,00
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
Battery SMA Sunny Island	2.517,37	1	2.517,37
TOTAL			17.109,04

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 29.



▾ With increased self-consumption (1xBattery)

Self-sufficiency quota

27.3 %

Self-consumption quota

75.6 %

Distribution of PV energy

Energy yield 7483 kWh

Grid feed-in 1826 kWh

Self-consumption 5658 kWh

Consumption 14246 kWh

Details

Energy yield of the PV plant	7483 kWh
Grid feed-in	1826 kWh
Consumption	14246 kWh
Self-consumption	5658 kWh
Self-consumption quota (in % of PV energy)	75.6 %
Self-sufficiency quota (energy consumption in %)	27.3 %
Annual battery cycles	138

Figure 29 Energy yield of a detached house without district heating with 9 kWh energy storage

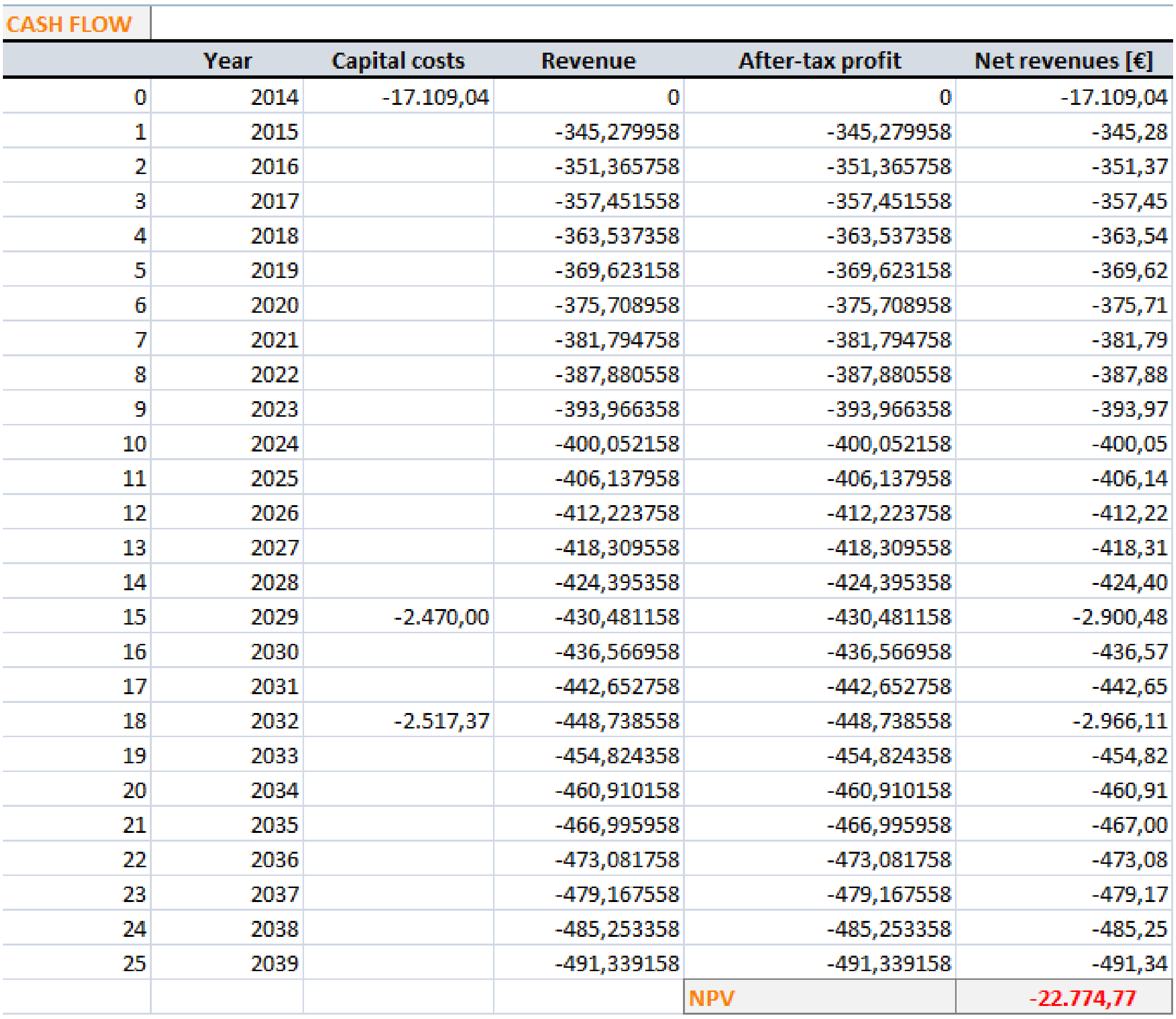
Out of 7483 kWh yielded from the PV system, 1826 kWh were fed into the grid. The rest (5658 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (14246 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 16.

In this case battery had 138 annual life cycles which means it had to be replaced in 2032 after 17 operational years.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house without district heating with 9 kWh energy storage in today’s environment in Trondheim.

Table 16Economic cash flow for a detached house without district heating with 9 kWh energy storage



CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-17.109,04	0	0	-17.109,04
1	2015		-345,279958	-345,279958	-345,28
2	2016		-351,365758	-351,365758	-351,37
3	2017		-357,451558	-357,451558	-357,45
4	2018		-363,537358	-363,537358	-363,54
5	2019		-369,623158	-369,623158	-369,62
6	2020		-375,708958	-375,708958	-375,71
7	2021		-381,794758	-381,794758	-381,79
8	2022		-387,880558	-387,880558	-387,88
9	2023		-393,966358	-393,966358	-393,97
10	2024		-400,052158	-400,052158	-400,05
11	2025		-406,137958	-406,137958	-406,14
12	2026		-412,223758	-412,223758	-412,22
13	2027		-418,309558	-418,309558	-418,31
14	2028		-424,395358	-424,395358	-424,40
15	2029	-2.470,00	-430,481158	-430,481158	-2.900,48
16	2030		-436,566958	-436,566958	-436,57
17	2031		-442,652758	-442,652758	-442,65
18	2032	-2.517,37	-448,738558	-448,738558	-2.966,11
19	2033		-454,824358	-454,824358	-454,82
20	2034		-460,910158	-460,910158	-460,91
21	2035		-466,995958	-466,995958	-467,00
22	2036		-473,081758	-473,081758	-473,08
23	2037		-479,167558	-479,167558	-479,17
24	2038		-485,253358	-485,253358	-485,25
25	2039		-491,339158	-491,339158	-491,34
				NPV	-22.774,77

5.4.3. Detached house without district heating with 20 kWh energy storage

In this case, initial costs (Table 17) are the same as for the detached house without district heating with 9 kWh energy storage, with added cost of two batteries (in total three SMA Sunny Island 6.0H batteries were installed).

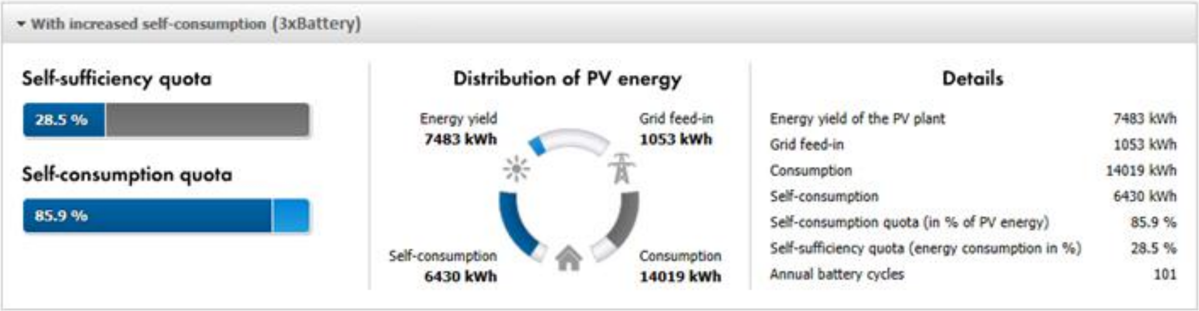
Table 17 Initial costs for a detached house with 20 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 4000 TL-21	1.235,00	2	2.470,00
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93

Connection to the grid	1.600,00	1	1.600,00
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
Battery SMA Sunny Island	2.517,37	3	7.552,11
TOTAL			22.143,78

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 30.

Out of 7483 kWh yielded from the PV system, 1053 kWh were fed into the grid. The rest (6430 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (14019 kWh), and yearly operational costs which are calculated as 1% of initial costs.



Energy yield of the PV plant	7483 kWh
Grid feed-in	1053 kWh
Consumption	14019 kWh
Self-consumption	6430 kWh
Self-consumption quota (in % of PV energy)	85.9 %
Self-sufficiency quota (energy consumption in %)	28.5 %
Annual battery cycles	101

Figure 30 Energy yield of a detached house without district heating with 9 kWh energy storage

Economic cash flow is presented in Table 18.

In this case batteries had 101 annual life cycles which means it had to be replaced in 2038 after 23 operational years.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house without district heating with 20 kWh energy storage in today’s environment in Trondheim.

Table 18 Economic cash flow for a detached house without district heating with 20 kWh energy storage

CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-22.143,78	0,00	0	-22.143,78
1	2015		-339,298349	-339,298349	-339,30
2	2016		-345,180749	-345,180749	-345,18
3	2017		-351,063149	-351,063149	-351,06
4	2018		-356,945549	-356,945549	-356,95
5	2019		-362,827949	-362,827949	-362,83
6	2020		-368,710349	-368,710349	-368,71
7	2021		-374,592749	-374,592749	-374,59
8	2022		-380,475149	-380,475149	-380,48
9	2023		-386,357549	-386,357549	-386,36
10	2024		-392,239949	-392,239949	-392,24
11	2025		-398,122349	-398,122349	-398,12
12	2026		-404,004749	-404,004749	-404,00
13	2027		-409,887149	-409,887149	-409,89
14	2028		-415,769549	-415,769549	-415,77
15	2029	-2.470,00	-421,651949	-421,651949	-2.891,65
16	2030		-427,534349	-427,534349	-427,53
17	2031		-433,416749	-433,416749	-433,42
18	2032		-439,299149	-439,299149	-439,30
19	2033		-445,181549	-445,181549	-445,18
20	2034		-451,063949	-451,063949	-451,06
21	2035		-456,946349	-456,946349	-456,95
22	2036		-462,828749	-462,828749	-462,83
23	2037		-468,711149	-468,711149	-468,71
24	2038	-7.552,11	-474,593549	-474,593549	-8.026,70
25	2039		-480,475949	-480,475949	-480,48
				NPV	-28.357,74

5.5. Detached house with district heating

A detached house with district heating has a yearly electricity consumption of 11.300 kWh.

Average daily profile of electricity consumption by season is shown on Figure 31 (source: SMA Sunny Design).

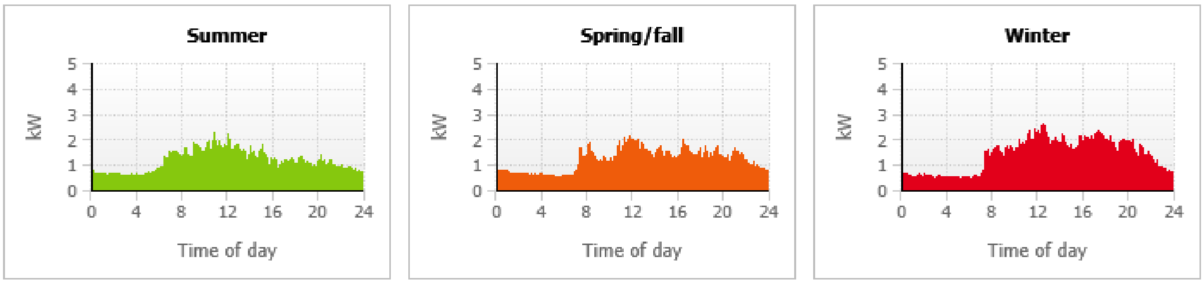
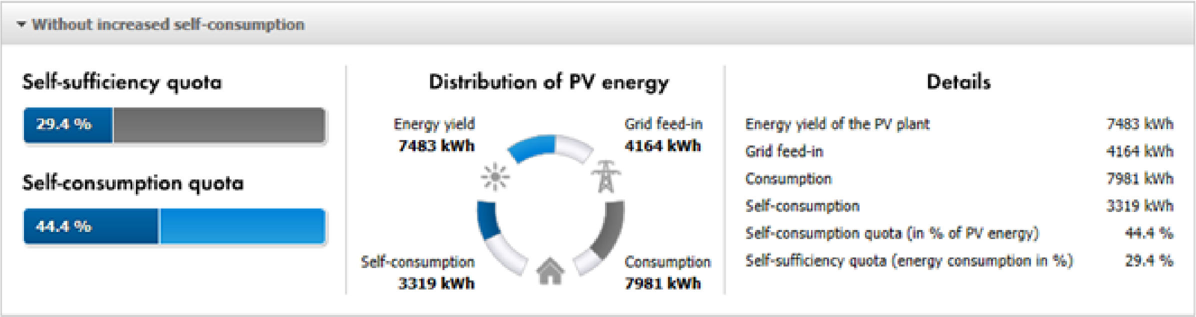


Figure 31Average daily profile of electricity consumption for a detached house with district heating in Trondheim

5.5.1. Detached house with district heating without energy storage

Initial costs are the same as for the case of a detached house without district heating without energy storage.

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 32.



▾ Without increased self-consumption

Self-sufficiency quota

29.4 %

Self-consumption quota

44.4 %

Distribution of PV energy

Energy yield **7483 kWh**

Grid feed-in **4164 kWh**

Self-consumption **3319 kWh**

Consumption **7981 kWh**

Details

Energy yield of the PV plant	7483 kWh
Grid feed-in	4164 kWh
Consumption	7981 kWh
Self-consumption	3319 kWh
Self-consumption quota (in % of PV energy)	44.4 %
Self-sufficiency quota (energy consumption in %)	29.4 %

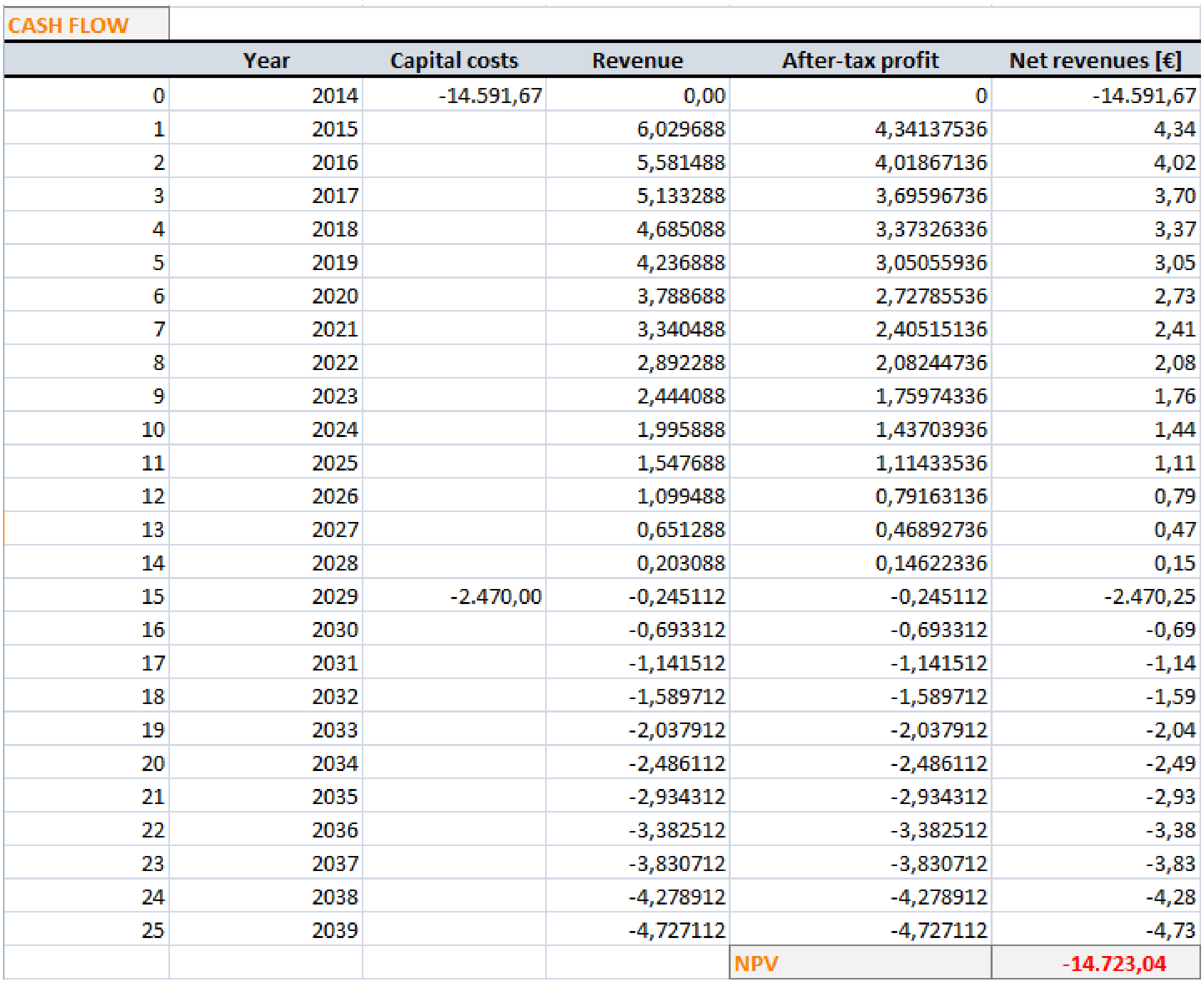
Figure 32 Energy yield of a detached house with district heating without energy storage

Out of 7483 kWh yielded from the PV system, 4164 kWh were fed into the grid. The rest (3319 kWh) is direct self-consumption since this case hasn’t got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (7981 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 19.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house with district heating without energy storage in today’s environment in Trondheim.

Table 19 Economic cash flow for a detached house with district heating without energy storage



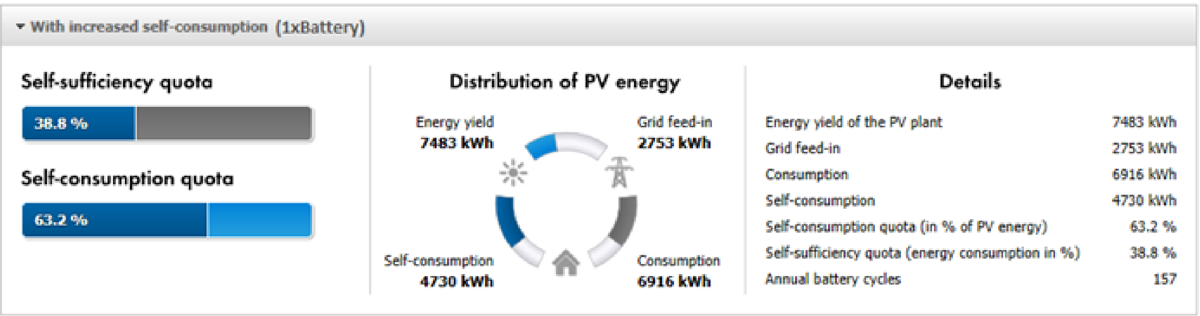
CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-14.591,67	0,00	0	-14.591,67
1	2015		6,029688	4,34137536	4,34
2	2016		5,581488	4,01867136	4,02
3	2017		5,133288	3,69596736	3,70
4	2018		4,685088	3,37326336	3,37
5	2019		4,236888	3,05055936	3,05
6	2020		3,788688	2,72785536	2,73
7	2021		3,340488	2,40515136	2,41
8	2022		2,892288	2,08244736	2,08
9	2023		2,444088	1,75974336	1,76
10	2024		1,995888	1,43703936	1,44
11	2025		1,547688	1,11433536	1,11
12	2026		1,099488	0,79163136	0,79
13	2027		0,651288	0,46892736	0,47
14	2028		0,203088	0,14622336	0,15
15	2029	-2.470,00	-0,245112	-0,245112	-2.470,25
16	2030		-0,693312	-0,693312	-0,69
17	2031		-1,141512	-1,141512	-1,14
18	2032		-1,589712	-1,589712	-1,59
19	2033		-2,037912	-2,037912	-2,04
20	2034		-2,486112	-2,486112	-2,49
21	2035		-2,934312	-2,934312	-2,93
22	2036		-3,382512	-3,382512	-3,38
23	2037		-3,830712	-3,830712	-3,83
24	2038		-4,278912	-4,278912	-4,28
25	2039		-4,727112	-4,727112	-4,73
				NPV	-14.723,04

5.5.2. Detached house with district heating with 9 kWh energy storage

Initial costs are the same as for the case of a detached house without district heating with 9 kWh energy storage

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 33.

Out of 7483 kWh yielded from the PV system, 2753 kWh were fed into the grid. The rest (4730 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (6916 kWh), and yearly operational costs which are calculated as 1% of initial costs.


▾ With increased self-consumption (1xBattery)

Self-sufficiency quota

38.8 %

Self-consumption quota

63.2 %

Distribution of PV energy

Details

Energy yield of the PV plant	7483 kWh
Grid feed-in	2753 kWh
Consumption	6916 kWh
Self-consumption	4730 kWh
Self-consumption quota (in % of PV energy)	63.2 %
Self-sufficiency quota (energy consumption in %)	38.8 %
Annual battery cycles	157

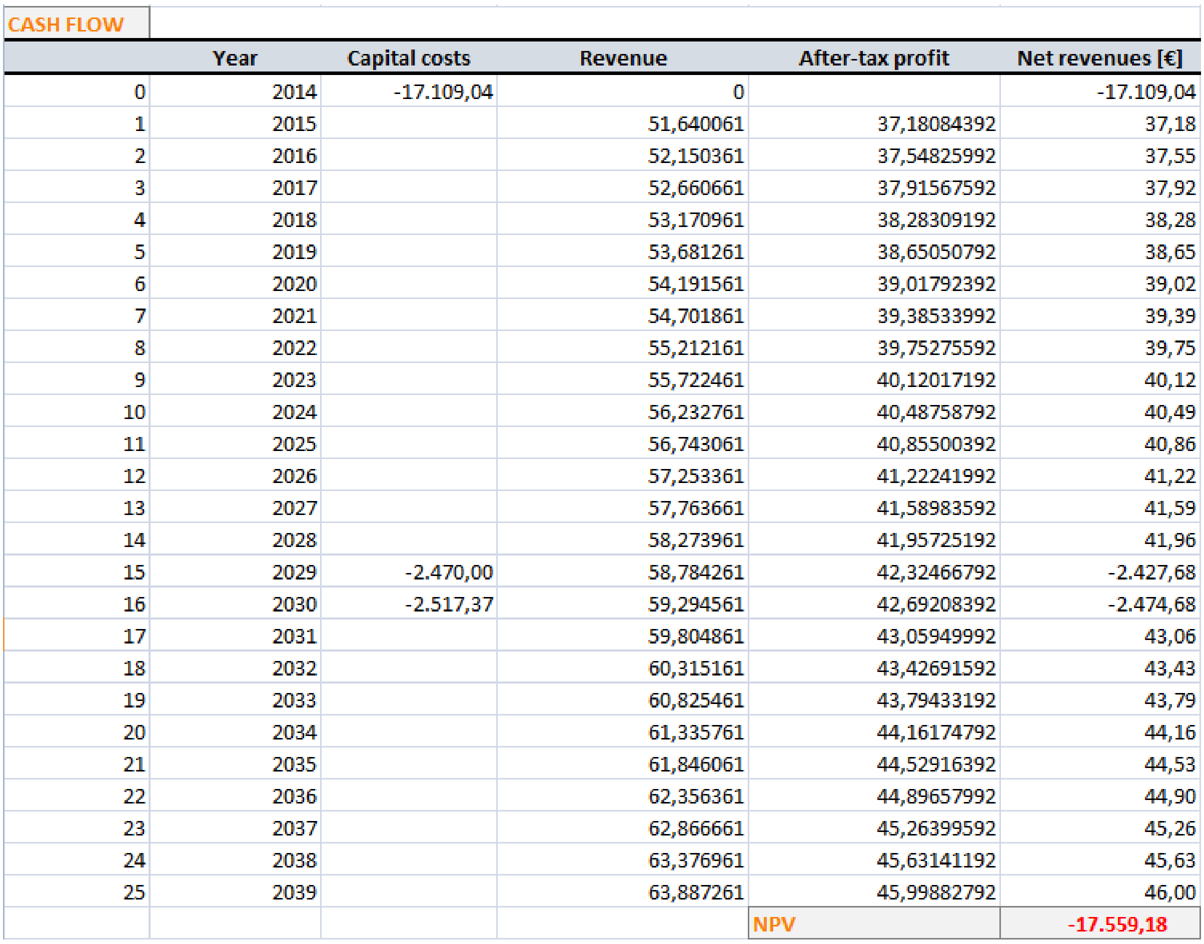
Figure 33 Energy yield of a detached house with district heating with 9 kWh energy storage

Economic cash flow is presented in Table 20.

In this case battery had 157 annual life cycles which means it had to be replaced in 2030 after 15 operational years.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house with district heating with 9 kWh energy storage in today’s environment in Trondheim.

Table 20 Economic cash flow for a detached house with district heating with 9 kWh energy storage

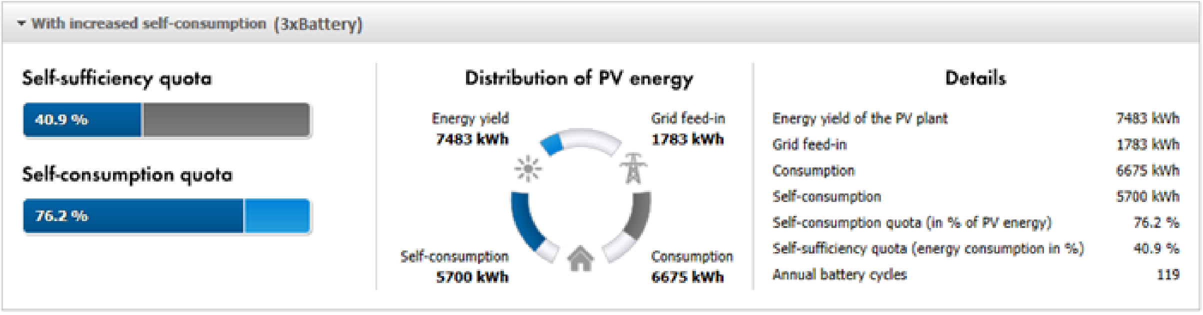

CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-17.109,04	0		-17.109,04
1	2015		51,640061	37,18084392	37,18
2	2016		52,150361	37,54825992	37,55
3	2017		52,660661	37,91567592	37,92
4	2018		53,170961	38,28309192	38,28
5	2019		53,681261	38,65050792	38,65
6	2020		54,191561	39,01792392	39,02
7	2021		54,701861	39,38533992	39,39
8	2022		55,212161	39,75275592	39,75
9	2023		55,722461	40,12017192	40,12
10	2024		56,232761	40,48758792	40,49
11	2025		56,743061	40,85500392	40,86
12	2026		57,253361	41,22241992	41,22
13	2027		57,763661	41,58983592	41,59
14	2028		58,273961	41,95725192	41,96
15	2029	-2.470,00	58,784261	42,32466792	-2.427,68
16	2030	-2.517,37	59,294561	42,69208392	-2.474,68
17	2031		59,804861	43,05949992	43,06
18	2032		60,315161	43,42691592	43,43
19	2033		60,825461	43,79433192	43,79
20	2034		61,335761	44,16174792	44,16
21	2035		61,846061	44,52916392	44,53
22	2036		62,356361	44,89657992	44,90
23	2037		62,866661	45,26399592	45,26
24	2038		63,376961	45,63141192	45,63
25	2039		63,887261	45,99882792	46,00
				NPV	-17.559,18

5.5.3. Detached house with district heating with 20 kWh energy storage

Initial costs are the same as for the case of a detached house without district heating with 20 kWh energy storage.

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 34.



With increased self-consumption (3xBattery)

Self-sufficiency quota

40.9 %

Self-consumption quota

76.2 %

Distribution of PV energy

Details

Energy yield of the PV plant	7483 kWh
Grid feed-in	1783 kWh
Consumption	6675 kWh
Self-consumption	5700 kWh
Self-consumption quota (in % of PV energy)	76.2 %
Self-sufficiency quota (energy consumption in %)	40.9 %
Annual battery cycles	119

Figure 34 Energy yield of a detached house with district heating with 20 kWh energy storage

Out of 7483 kWh yielded from the PV system, 1783 kWh were fed into the grid. The rest (5700 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (6675 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 21.

In this case batteries had 119 annual life cycles which means it had to be replaced in 2035 after 20 operational years.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house with district heating with 20 kWh energy storage in today’s environment in Trondheim.

Table 21Economic cash flow for a detached house with district heating with 20 kWh energy storage

CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-22.143,78	0		-22.143,78
1	2015		56,881241	40,95449352	56,88
2	2016		57,608441	41,47807752	57,61
3	2017		58,335641	42,00166152	58,34
4	2018		59,062841	42,52524552	59,06
5	2019		59,790041	43,04882952	59,79
6	2020		60,517241	43,57241352	60,52
7	2021		61,244441	44,09599752	61,24
8	2022		61,971641	44,61958152	61,97
9	2023		62,698841	45,14316552	62,70
10	2024		63,426041	45,66674952	63,43
11	2025		64,153241	46,19033352	64,15
12	2026		64,880441	46,71391752	64,88
13	2027		65,607641	47,23750152	65,61
14	2028		66,334841	47,76108552	66,33
15	2029	-2.470,00	67,062041	48,28466952	-2.402,94
16	2030		67,789241	48,80825352	67,79
17	2031		68,516441	49,33183752	68,52
18	2032		69,243641	49,85542152	69,24
19	2033		69,970841	50,37900552	69,97
20	2034		70,698041	50,90258952	70,70
21	2035	-7.552,11	71,425241	51,42617352	-7.480,68
22	2036		72,152441	51,94975752	72,15
23	2037		72,879641	52,47334152	72,88
24	2038		73,606841	52,99692552	73,61
25	2039		74,334041	53,52050952	74,33
				NPV	-23.192,88

5.6. Discussion of results for Trondheim

All of the examined cases had negative net present value, which means that they are not profitable for implementation in today’s market conditions. Main issue here are not initial costs because they will decrease as the technology rapidly evolves. For instance, learning curve for PV panels predicts that the price per watt will drop 30% until 2018 (Figure 35).

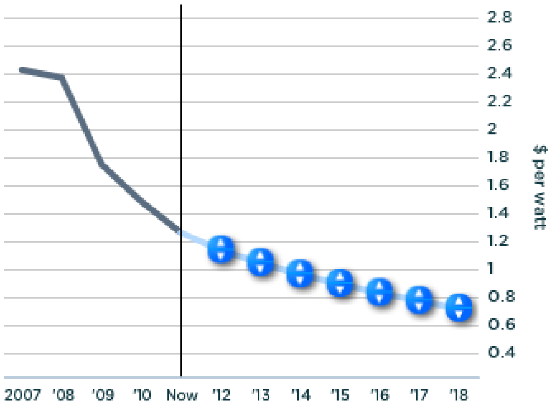


Figure 35 PV panels learning curve[54]

Problem with the conducted analysis is that the projects gained very little or none yearly revenues. This can be improved with higher green certificate price. That way smart households would gain more profit from selling electricity to the grid. Also, they need to decrease their total energy consumption. That can be done by improving building envelope so that less electricity is needed in cases without the district heating. Also, new generations of home appliances offer improved energy efficiency and more savings in that sense.

Furthermore, DSOs should start offering a Time of Day (ToD) tariffs for households. There have been a lot of pilot projects that confirmed benefits of such agreement.

In one of the pilot studies, implemented at Malvik Everk, a DSO in Central-Norway, 40 household customers were given hourly metering of their electricity consumption with use of existing AMR technology and access to the web site with information about their network costs with the ToD network tariff, compared with the traditional network tariff.

Registered average demand response during morning peak load was approximately 1 kWh/h for customers with standard electrical water heaters (non-electrical space heating) and approximately 2,5 kWh/h for customers with hot water space heating systems with electrical boilers [55].

The DSO had to get an exemption from today’s regulations to be able to offer the ToD network tariff used in the pilot study. Therefore the ToD network tariff is not a tariff that can be offered to customers at a large scale today.

6. Smart households in Split

Another way to increase yearly revenues is higher PV system production. Without the increase of initial project costs, that can be done by implementing smart household in areas with greater insolation. Other benefit from ”moving further south” is decreased electricity end-consumption due to less energy needed for space heating.

For conducting further analysis in that direction, Split in Croatia has been selected. Since this paper is written in collaboration with Faculty of electrical engineering and computing, University of Zagreb, Croatia, the idea was to select the biggest city in that country which has a great insolation rate.

Split is the second largest city in Croatia and the largest Croatian city on the eastern coast of the Adriatic Sea with 178.102 inhabitants (very similar to Trondheim) [56]. It is well known for its mild climate, measurable through 2700 hours of sunshine yearly[57]. This makes it a great candidate for installing PV systems.

Five cases of different energy consumption, production and storage have been investigated, equipped in the same way as Trondheim’s households for comparison. Since households in Split don’t have a district heating option, those cases are excluded from this analysis.

6.1. Croatian household consumption

Electricity consumption of households in Croatia accounts for 6.464,4 GWh/year as presented on Figure 36.

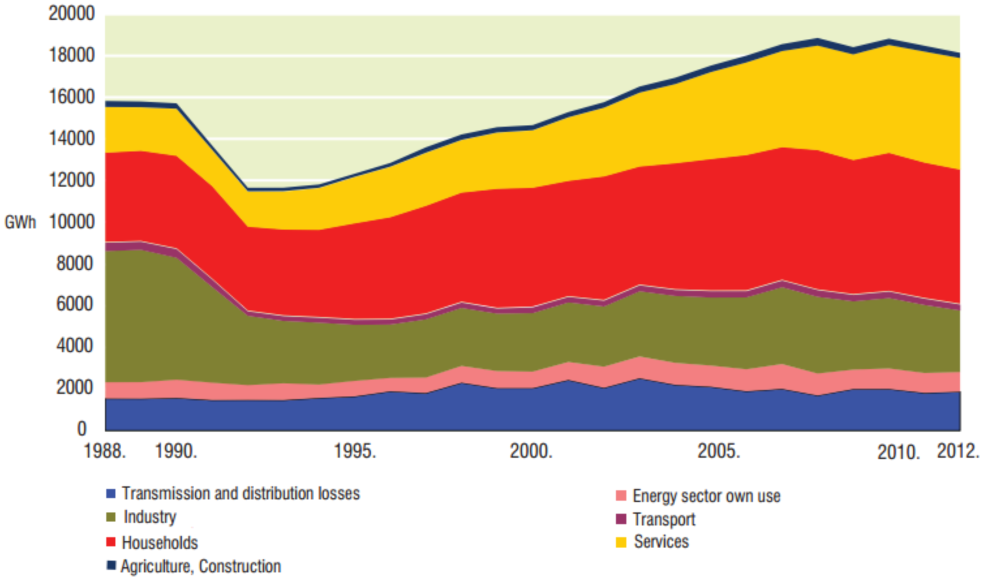


Figure 36 Electricity consumption in the Republic of Croatia [58]

That accounts for 31% of total electricity consumption, which makes this sector extremely important for improving energy efficiency. Detached houses and houses with 2 dwellings represent about 65%, and multi-dwelling building about 35% of total housing stock [59].

Electricity end-use breakdown for an average Croatian household is shown on Figure 37. Space heating (if it is electricity-based) and hot water amount to about 68% of the electricity consumption. Next up is electronics with 15% and cooking and washing with 13%. Cooling and lighting together use about 6%. Same as in Norway, improving building envelope would offer great energy and financial savings since great amount of energy is used for space heating. This is also magnified by the fact that 43% of Croatian households were built before 1970, just when prescribed measures and conditions for thermal protection of buildings came into force [59].

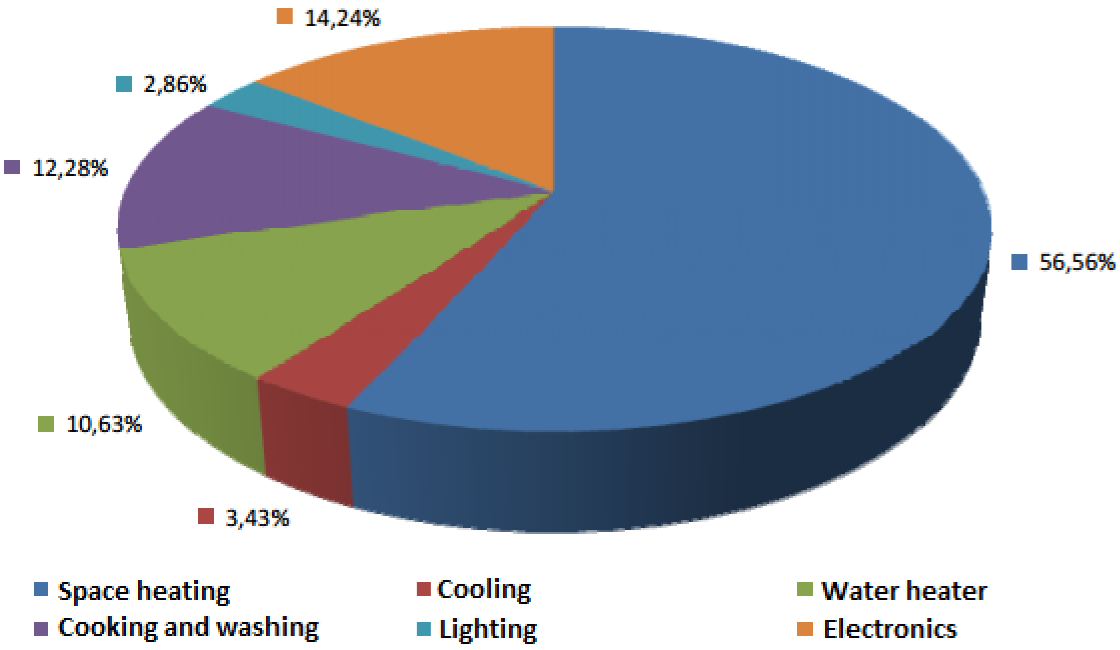


Figure 37 Percent shares of electrical end-use in Croatian household [59]

Average electricity consumption in Croatian household is 3.000 kWh. It is due to the fact that, in continental part of the country, electricity isn’t used as primary heating source. Thermal energy for space heating is largely provided by the firewood (45%), and then the natural gas (25%), oil (9%) and electrical energy (13%) [59]. In the coastal part of the country, most households use electricity for heating, because there is no natural gas distribution infrastructure. That is why average electricity consumption is around 4.000 kWh [60].

6.2. Croatian electricity pricing

Although initial costs for Croatia are almost the same as for Norway, there is a great difference in yearly revenues. It is partially because smart households in Split (for the same PV system capacity installed) yield48% more electricity every year. Other main difference is fixed incentive prices for grid feed-in from renewable energy sources.

Incentive price for PV on-grid systems up to 10 kW of installed capacity is 0,25 €/kWh [61]. This incentive price is assured for the first 14 years of system operation after signing a contract with Croatian energy market operator (HROTE).

After the incentive period electricity is sold to the grid by much smaller rate of 0,0702€/kWh [62]. This is the so-called PPC (average production cost).

In terms of buying the rest of the need electricity which is not being met by the self-consumption, it is purchased at the rate of 0,0734 €/kWh [63]. This is a blue one-tariff household pricing from the national supplier HEP Opskrba.

6.3. Apartment

An apartment in Split has an average yearly electricity consumption of 4.000 kWh [60].

Average daily profile of electricity consumption by season is shown on Figure 38 (source: SMA Sunny Design).

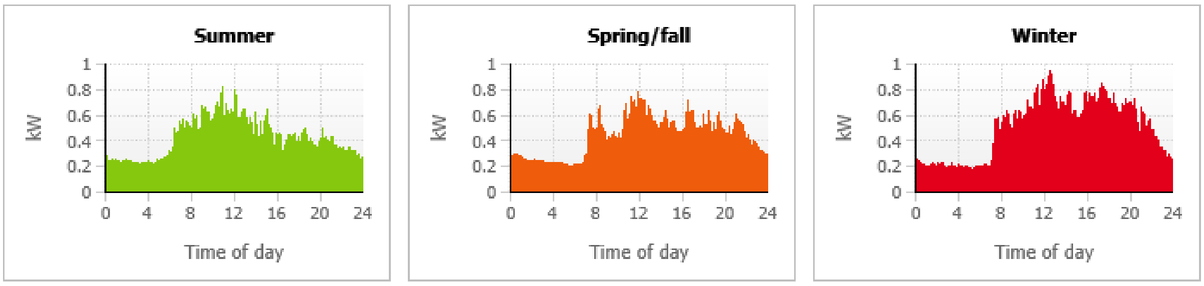


Figure 38 Average daily profile of electricity consumption for an apartment in Split

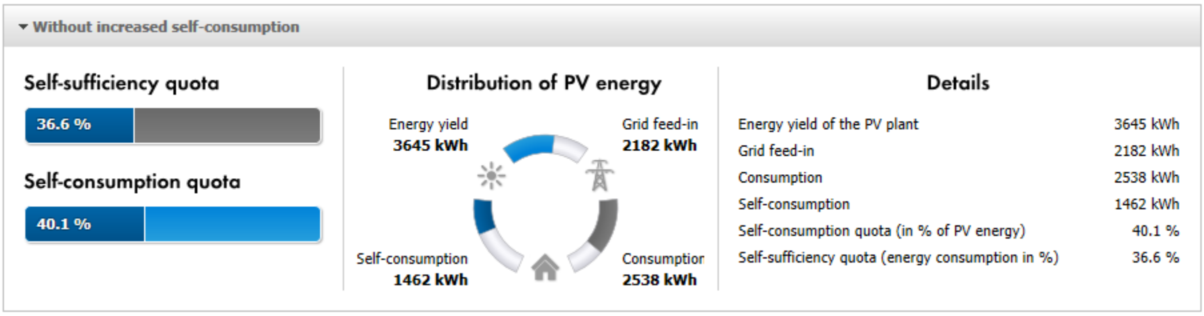
6.3.1. Apartment without energy storage

Initial costs shown in Table 22 are the same as for the case of an apartment without energy storage in Trondheim, with a small difference in cost of grid connection[64].

Table 22 Initial costs for an apartment without energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	10	1.936,60
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.451,98	1	1.451,98
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	30	70,50
TOTAL			6.954,31

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 39.



▾ Without increased self-consumption

Self-sufficiency quota

36.6 %

Self-consumption quota

40.1 %

Distribution of PV energy

Energy yield 3645 kWh

Grid feed-in 2182 kWh

Self-consumption 1462 kWh

Consumption 2538 kWh

Details

Energy yield of the PV plant	3645 kWh
Grid feed-in	2182 kWh
Consumption	2538 kWh
Self-consumption	1462 kWh
Self-consumption quota (in % of PV energy)	40.1 %
Self-sufficiency quota (energy consumption in %)	36.6 %

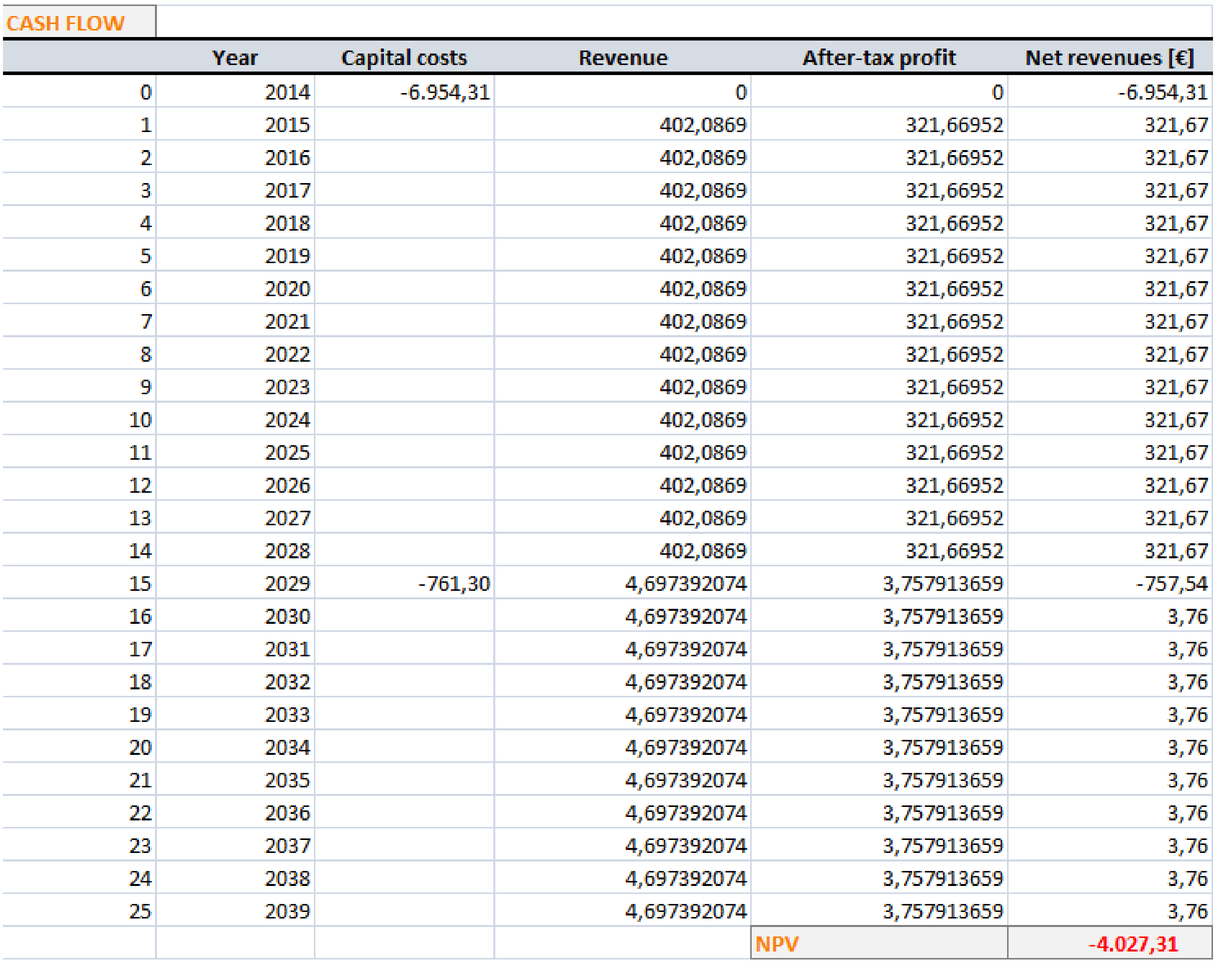
Figure 39Energy yield of an apartment without energy storage in Split

Out of 3645 kWh yielded from the PV system, 2182 kWh were fed into the grid. The rest (1462 kWh) is direct self-consumption since this case hasn’t got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (2538 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 23.

After calculating revenues they have been taxed with a 20% rate of Croatian income tax [65].

Table 23Economic cash flow for an apartment without energy storage in Split



CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-6.954,31	0	0	-6.954,31
1	2015		402,0869	321,66952	321,67
2	2016		402,0869	321,66952	321,67
3	2017		402,0869	321,66952	321,67
4	2018		402,0869	321,66952	321,67
5	2019		402,0869	321,66952	321,67
6	2020		402,0869	321,66952	321,67
7	2021		402,0869	321,66952	321,67
8	2022		402,0869	321,66952	321,67
9	2023		402,0869	321,66952	321,67
10	2024		402,0869	321,66952	321,67
11	2025		402,0869	321,66952	321,67
12	2026		402,0869	321,66952	321,67
13	2027		402,0869	321,66952	321,67
14	2028		402,0869	321,66952	321,67
15	2029	-761,30	4,697392074	3,757913659	-757,54
16	2030		4,697392074	3,757913659	3,76
17	2031		4,697392074	3,757913659	3,76
18	2032		4,697392074	3,757913659	3,76
19	2033		4,697392074	3,757913659	3,76
20	2034		4,697392074	3,757913659	3,76
21	2035		4,697392074	3,757913659	3,76
22	2036		4,697392074	3,757913659	3,76
23	2037		4,697392074	3,757913659	3,76
24	2038		4,697392074	3,757913659	3,76
25	2039		4,697392074	3,757913659	3,76
				NPV	**-4.027,31**

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart apartment without energy storage in today's environment in Split.

6.3.2. Apartment with 9 kWh energy storage

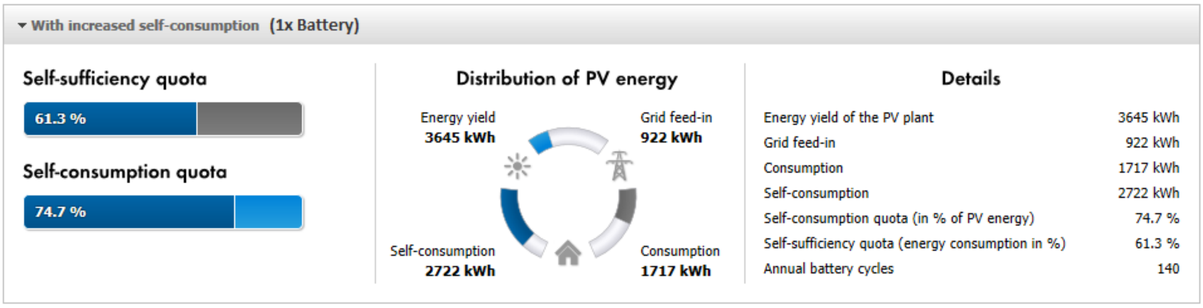
In this case, initial costs are the same as for the apartment without energy storage, with added cost of energy storage system (Table 24).

Table 24 Initial costs for an apartment with 9 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	10	1.936,60
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.451,98	1	1.451,98

Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	30	70,50
Battery SMA Sunny Island	2.517,37	1	2.517,37
TOTAL			9.471,68

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 40.


With increased self-consumption (1x Battery)

Self-sufficiency quota
61.3 %

Self-consumption quota
74.7 %

Distribution of PV energy
Energy yield 3645 kWh
Grid feed-in 922 kWh
Self-consumption 2722 kWh
Consumption 1717 kWh

Details

Energy yield of the PV plant	3645 kWh
Grid feed-in	922 kWh
Consumption	1717 kWh
Self-consumption	2722 kWh
Self-consumption quota (in % of PV energy)	74.7 %
Self-sufficiency quota (energy consumption in %)	61.3 %
Annual battery cycles	140

Figure 40 Energy yield of an apartment with 9 kWh energy storage in Split

Out of 3645 kWh yielded from the PV system, 922 kWh were fed into the grid. The rest (2722 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (1717 kWh), and yearly operational costs which are calculated as 1% of initial costs.

In this case battery had 140 annual life cycles which means it had to be replaced in 2031 after 16 operational years.

Economic cash flow is presented in Table 25.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart apartment with 9 kWh energy storage in today’s environment in Split.

Table 25Economic cash flow for an apartment with 9 kWh energy storage in Split

CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-9.471,68	0	0	-9.471,68
1	2015		211,6472372	169,3177897	169,32
2	2016		211,6472372	169,3177897	169,32
3	2017		211,6472372	169,3177897	169,32
4	2018		211,6472372	169,3177897	169,32
5	2019		211,6472372	169,3177897	169,32
6	2020		211,6472372	169,3177897	169,32
7	2021		211,6472372	169,3177897	169,32
8	2022		211,6472372	169,3177897	169,32
9	2023		211,6472372	169,3177897	169,32
10	2024		211,6472372	169,3177897	169,32
11	2025		211,6472372	169,3177897	169,32
12	2026		211,6472372	169,3177897	169,32
13	2027		211,6472372	169,3177897	169,32
14	2028		211,6472372	169,3177897	169,32
15	2029	-761,30	43,7310473	34,98483784	-726,32
16	2030		43,7310473	34,98483784	34,98
17	2031	-2.517,37	43,7310473	34,98483784	-2.482,39
18	2032		43,7310473	34,98483784	34,98
19	2033		43,7310473	34,98483784	34,98
20	2034		43,7310473	34,98483784	34,98
21	2035		43,7310473	34,98483784	34,98
22	2036		43,7310473	34,98483784	34,98
23	2037		43,7310473	34,98483784	34,98
24	2038		43,7310473	34,98483784	34,98
25	2039		43,7310473	34,98483784	34,98
				NPV	-8.517,32

6.4. Detached house

A detached house in Split has an average yearly electricity consumption of 6.265 kWh ([58],[56]).

Average daily profile of electricity consumption by season is shown on Figure 41 (source: SMA Sunny Design).

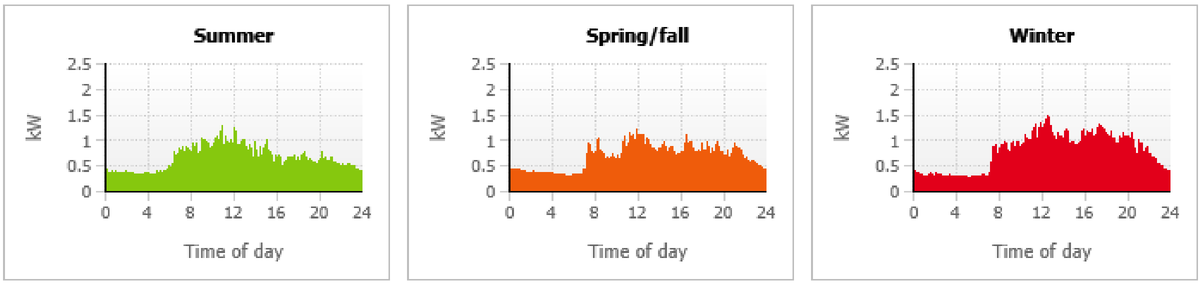


Figure 41 Average daily profile of electricity consumption for a detached house in Split

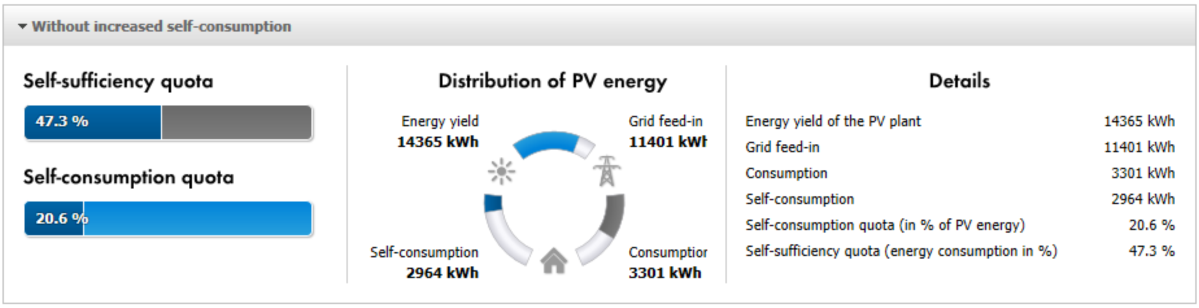
6.4.1. Detached house without energy storage

Initial costs shown in Table 26 are the same as for the case of a detached house without energy storage in Trondheim, with a small difference in cost of grid connection.

Table 26Initial costs for a detached house without energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 4000 TL-21	1.235,00	2	2.470,00
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.451,98	1	1.451,98
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
TOTAL			14.443,65

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 42.



▾ Without increased self-consumption

Self-sufficiency quota

47.3 %

Self-consumption quota

20.6 %

Distribution of PV energy

Details

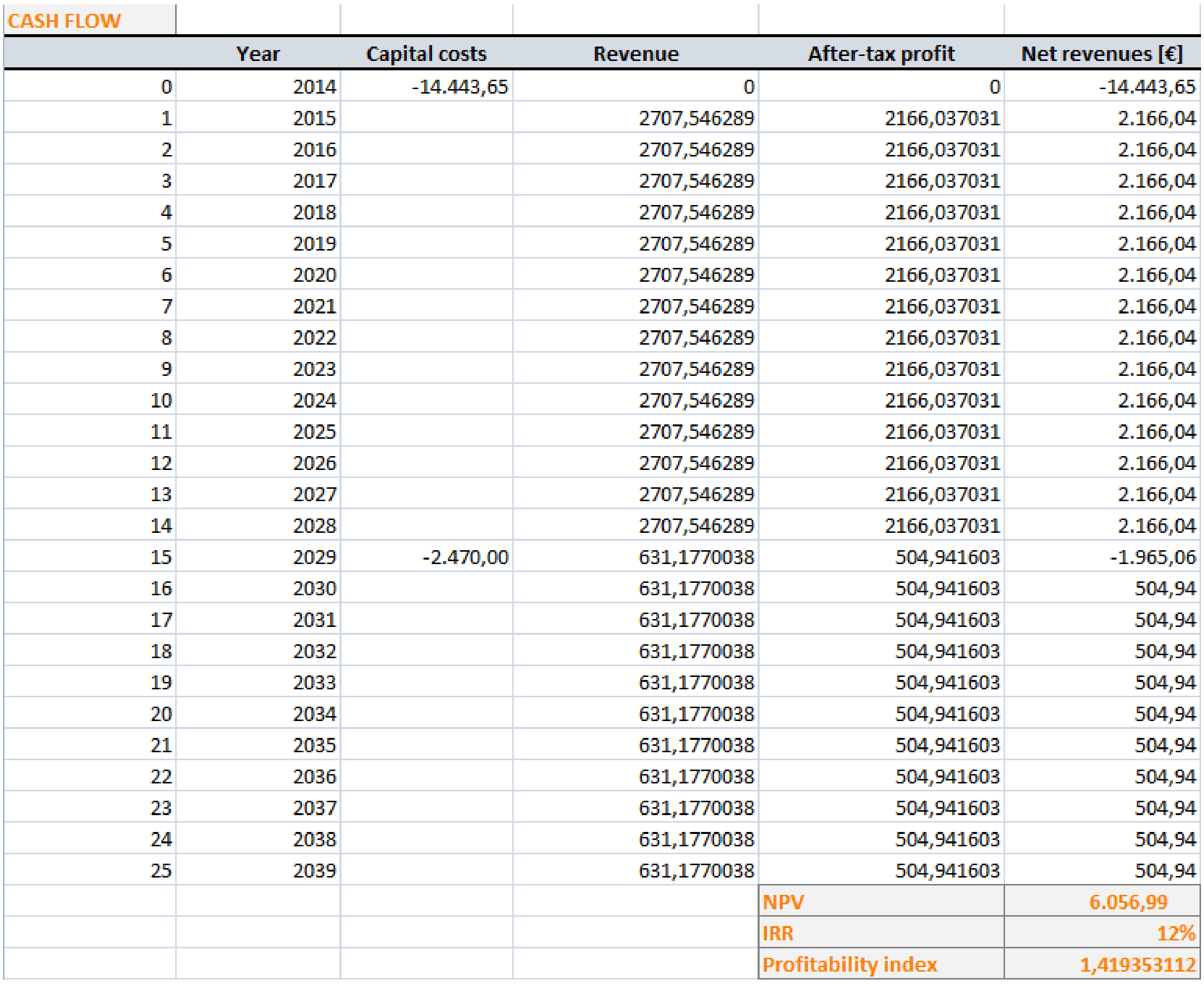
Energy yield of the PV plant	14365 kWh
Grid feed-in	11401 kWh
Consumption	3301 kWh
Self-consumption	2964 kWh
Self-consumption quota (in % of PV energy)	20.6 %
Self-sufficiency quota (energy consumption in %)	47.3 %

Figure 42Energy yield of a detached house without energy storage in Split

Out of 14365 kWh yielded from the PV system, 11401 kWh were fed into the grid. The rest (2964 kWh) is direct self-consumption since this case hasn't got any energy storage system installed. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (3301 kWh), and yearly operational costs which are calculated as 1% of initial costs.

Economic cash flow is presented in Table 23.

Table 27 Economic cash flow for an apartment without energy storage in Split



CASH FLOW					
	Year	**Capital costs**	**Revenue**	**After-tax profit**	**Net revenues [€]**
0	2014	-14.443,65	0	0	-14.443,65
1	2015		2707,546289	2166,037031	2.166,04
2	2016		2707,546289	2166,037031	2.166,04
3	2017		2707,546289	2166,037031	2.166,04
4	2018		2707,546289	2166,037031	2.166,04
5	2019		2707,546289	2166,037031	2.166,04
6	2020		2707,546289	2166,037031	2.166,04
7	2021		2707,546289	2166,037031	2.166,04
8	2022		2707,546289	2166,037031	2.166,04
9	2023		2707,546289	2166,037031	2.166,04
10	2024		2707,546289	2166,037031	2.166,04
11	2025		2707,546289	2166,037031	2.166,04
12	2026		2707,546289	2166,037031	2.166,04
13	2027		2707,546289	2166,037031	2.166,04
14	2028		2707,546289	2166,037031	2.166,04
15	2029	-2.470,00	631,1770038	504,941603	-1.965,06
16	2030		631,1770038	504,941603	504,94
17	2031		631,1770038	504,941603	504,94
18	2032		631,1770038	504,941603	504,94
19	2033		631,1770038	504,941603	504,94
20	2034		631,1770038	504,941603	504,94
21	2035		631,1770038	504,941603	504,94
22	2036		631,1770038	504,941603	504,94
23	2037		631,1770038	504,941603	504,94
24	2038		631,1770038	504,941603	504,94
25	2039		631,1770038	504,941603	504,94
				NPV	6.056,99
				IRR	12%
				Profitability index	1,419353112

From the economic cash flow, net present value was calculated and it was obtained that it is positive. This means that it is profitable to implement a smart detached house without energy storage in today’s environment in Split. In addition to that 12% IRR was calculated as well as the profitability index of 1,42 which indicates that this project is highly profitable.

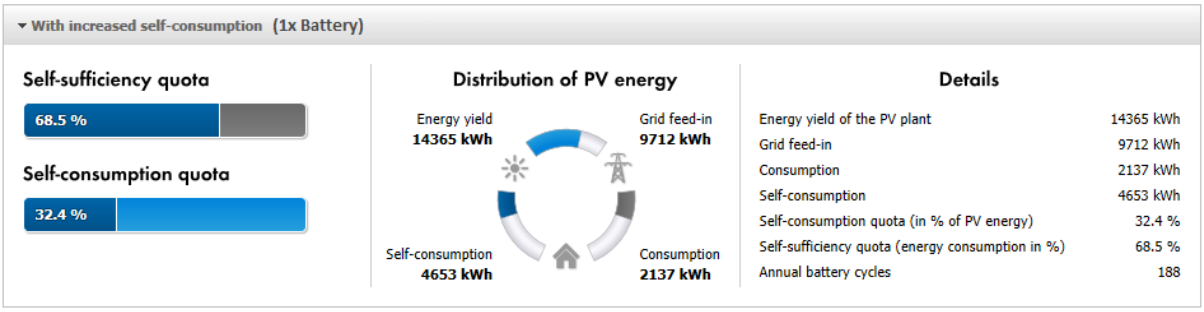
6.4.2. Detached house with 9 kWh energy storage

In this case, initial costs are the same as for the detached house without energy storage, with added cost of energy storage system (Table 28).

Table 28 Initial costs for a detached house with 9 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.451,98	1	1.451,98
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
Battery SMA Sunny Island	2.517,37	1	2.517,37
TOTAL			16.961,02

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 43.



With increased self-consumption (1x Battery)

Self-sufficiency quota

68.5 %

Self-consumption quota

32.4 %

Distribution of PV energy

Energy yield
14365 kWh

Grid feed-in
9712 kWh

Self-consumption
4653 kWh

Consumption
2137 kWh

Details

Energy yield of the PV plant	14365 kWh
Grid feed-in	9712 kWh
Consumption	2137 kWh
Self-consumption	4653 kWh
Self-consumption quota (in % of PV energy)	32.4 %
Self-sufficiency quota (energy consumption in %)	68.5 %
Annual battery cycles	188

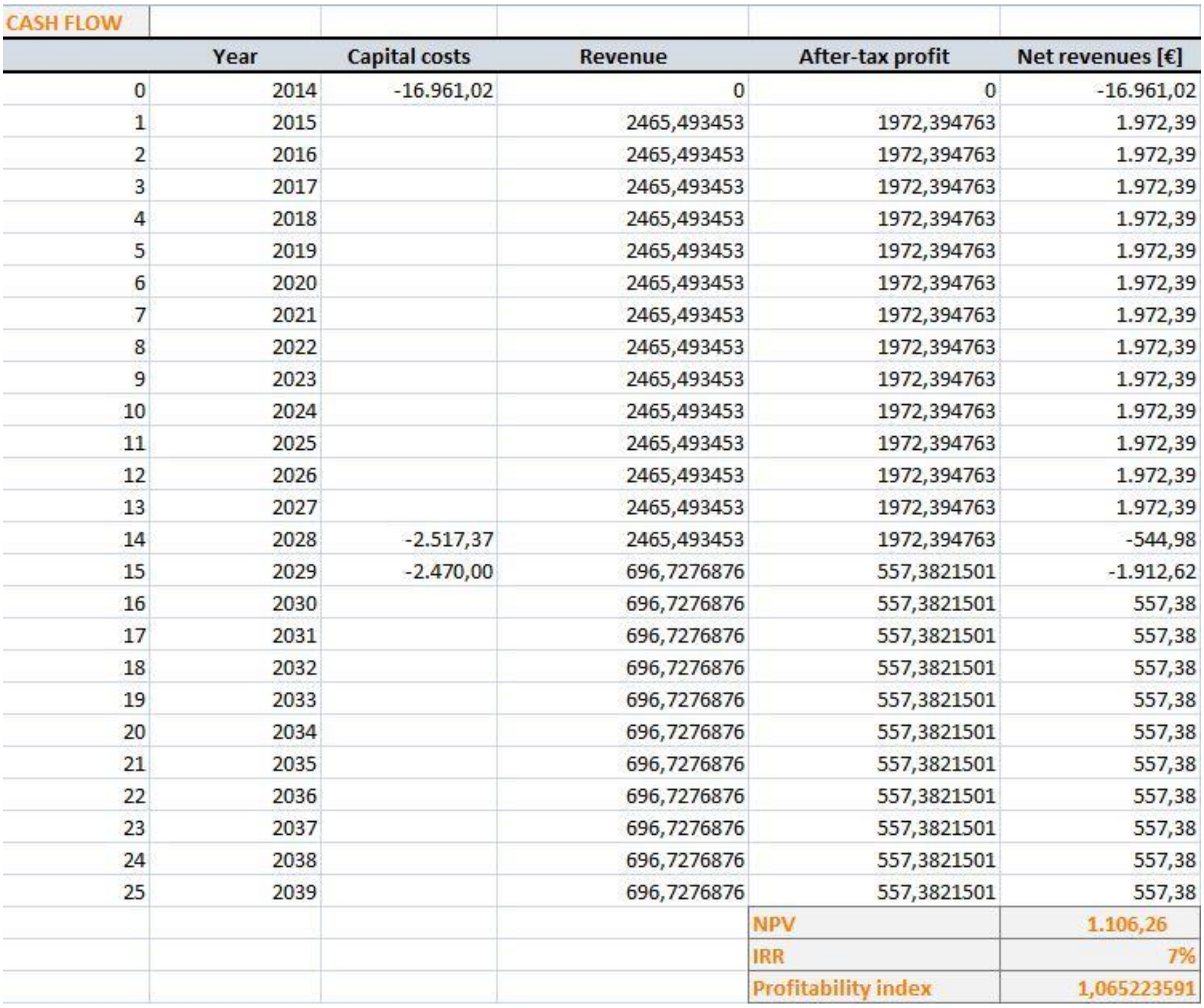
Figure 43 Energy yield of a detached house with 9 kWh energy storage in Split

Out of 14365 kWh yielded from the PV system, 9712 kWh were fed into the grid. The rest (4653 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (2137 kWh), and yearly operational costs which are calculated as 1% of initial costs.

In this case battery had 188 annual life cycles which means it had to be replaced in 2031 after 13 operational years.

Economic cash flow is presented in Table 29.

Table 29 Economic cash flow for a detached house with 9 kWh energy storage in Split



CASH FLOW					
	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-16.961,02	0	0	-16.961,02
1	2015		2465,493453	1972,394763	1.972,39
2	2016		2465,493453	1972,394763	1.972,39
3	2017		2465,493453	1972,394763	1.972,39
4	2018		2465,493453	1972,394763	1.972,39
5	2019		2465,493453	1972,394763	1.972,39
6	2020		2465,493453	1972,394763	1.972,39
7	2021		2465,493453	1972,394763	1.972,39
8	2022		2465,493453	1972,394763	1.972,39
9	2023		2465,493453	1972,394763	1.972,39
10	2024		2465,493453	1972,394763	1.972,39
11	2025		2465,493453	1972,394763	1.972,39
12	2026		2465,493453	1972,394763	1.972,39
13	2027		2465,493453	1972,394763	1.972,39
14	2028	-2.517,37	2465,493453	1972,394763	-544,98
15	2029	-2.470,00	696,7276876	557,3821501	-1.912,62
16	2030		696,7276876	557,3821501	557,38
17	2031		696,7276876	557,3821501	557,38
18	2032		696,7276876	557,3821501	557,38
19	2033		696,7276876	557,3821501	557,38
20	2034		696,7276876	557,3821501	557,38
21	2035		696,7276876	557,3821501	557,38
22	2036		696,7276876	557,3821501	557,38
23	2037		696,7276876	557,3821501	557,38
24	2038		696,7276876	557,3821501	557,38
25	2039		696,7276876	557,3821501	557,38
				NPV	1.106,26
				IRR	7%
				Profitability index	1,065223591

From the economic cash flow, net present value was calculated and it was obtained that it is positive. This means that it is profitable to implement a smart detached house with 9 kWh energy storage in today's environment in Split. In addition to that 7% IRR was calculated as well as the profitability index of 1,07 which indicates that this project is barely profitable but still gains small amount of profit at the end of its life cycle.

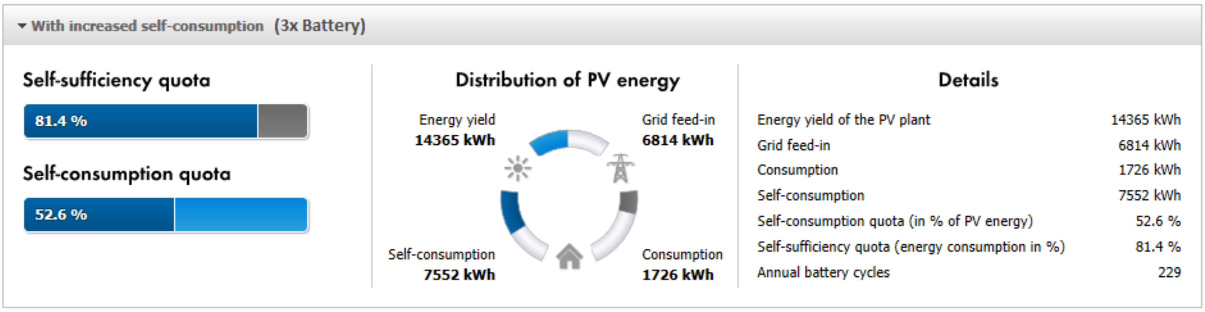
6.4.3. Detached house with 20 kWh energy storage

In this case, initial costs (Table 30) are the same as for the detached house with 9 kWh energy storage, with added cost of two batteries (in total three SMA Sunny Island 6.0H batteries were installed).

Table 30Initial costs for a detached house with 20 kWh energy storage

ITEM	PRICE PER ITEM [€]	QUANTITY	TOTAL COST [€]
Solar panels REC 250PE	193,66	39	7.552,74
Inverter SMA SB 2100 TL	761,30	1	761,30
SMA Energy Meter	323,00	1	323,00
Sunny home manager	310,93	1	310,93
Connection to the grid	1.451,98	1	1.451,98
Other specific costs	2.100,00	1	2.100,00
Copper cables per m	2,35	100	235,00
Battery SMA Sunny Island	2.517,37	3	7.552,11
TOTAL			21.995,76

SMA Sunny design software provided yearly energy self-consumption and generation for this case as shown on Figure 44.



▾ With increased self-consumption (3x Battery)

Self-sufficiency quota

81.4 %

Self-consumption quota

52.6 %

Distribution of PV energy

Energy yield **14365 kWh**

Grid feed-in **6814 kWh**

Self-consumption **7552 kWh**

Consumption **1726 kWh**

Details

Energy yield of the PV plant	14365 kWh
Grid feed-in	6814 kWh
Consumption	1726 kWh
Self-consumption	7552 kWh
Self-consumption quota (in % of PV energy)	52.6 %
Self-sufficiency quota (energy consumption in %)	81.4 %
Annual battery cycles	229

Figure 44 Energy yield of a detached house with 20 kWh energy storage in Split

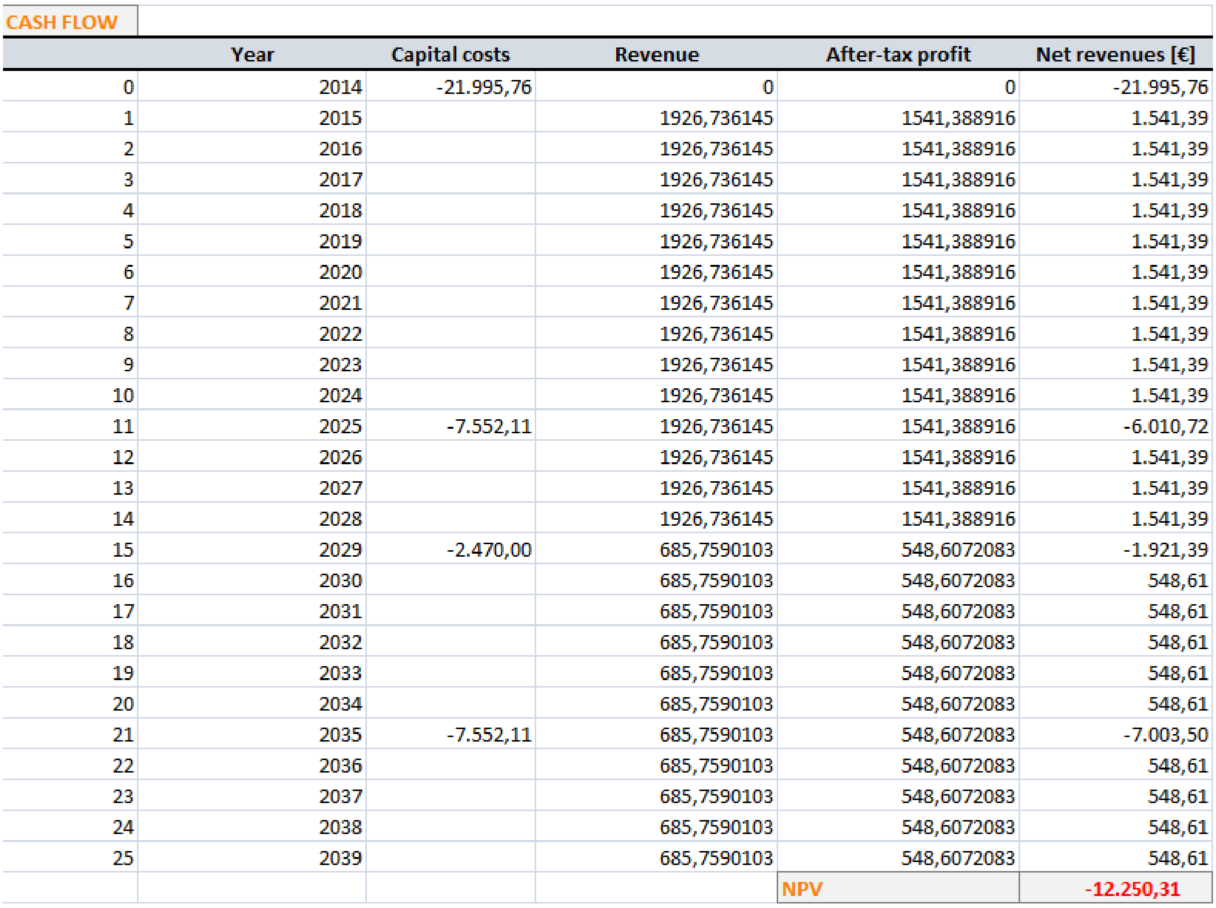
Out of 14365 kWh yielded from the PV system, 6814 kWh were fed into the grid. The rest (7552 kWh) has been stored and used later on. These make up yearly revenues reduced by the cost of additional electricity bought from the supplier (1726 kWh), and yearly operational costs which are calculated as 1% of initial costs.

In this case batteries had 229 annual life cycles which means they had to be replaced twice (in 2025 and in 2035), each time after 10 operational years.

Economic cash flow is presented in Table 31.

From the economic cash flow, net present value was calculated and it was obtained that it is negative. This means that it is not profitable to implement a smart detached house with 20 kWh energy storage in today’s environment in Split.

Table 31Economic cash flow for a detached house with 20 kWh energy storage in Split



CASH FLOW

	Year	Capital costs	Revenue	After-tax profit	Net revenues [€]
0	2014	-21.995,76	0	0	-21.995,76
1	2015		1926,736145	1541,388916	1.541,39
2	2016		1926,736145	1541,388916	1.541,39
3	2017		1926,736145	1541,388916	1.541,39
4	2018		1926,736145	1541,388916	1.541,39
5	2019		1926,736145	1541,388916	1.541,39
6	2020		1926,736145	1541,388916	1.541,39
7	2021		1926,736145	1541,388916	1.541,39
8	2022		1926,736145	1541,388916	1.541,39
9	2023		1926,736145	1541,388916	1.541,39
10	2024		1926,736145	1541,388916	1.541,39
11	2025	-7.552,11	1926,736145	1541,388916	-6.010,72
12	2026		1926,736145	1541,388916	1.541,39
13	2027		1926,736145	1541,388916	1.541,39
14	2028		1926,736145	1541,388916	1.541,39
15	2029	-2.470,00	685,7590103	548,6072083	-1.921,39
16	2030		685,7590103	548,6072083	548,61
17	2031		685,7590103	548,6072083	548,61
18	2032		685,7590103	548,6072083	548,61
19	2033		685,7590103	548,6072083	548,61
20	2034		685,7590103	548,6072083	548,61
21	2035	-7.552,11	685,7590103	548,6072083	-7.003,50
22	2036		685,7590103	548,6072083	548,61
23	2037		685,7590103	548,6072083	548,61
24	2038		685,7590103	548,6072083	548,61
25	2039		685,7590103	548,6072083	548,61
				NPV	-12.250,31

6.5. Discussion of results for Split

As the conducted cost benefit analysis shows, in case of Split, positive results have been obtained. Detached house without any energy storage turns out to be a profitable option. Also, implementing a smart house with 9 kWh of storage capacity isn’t highly profitable but still gains positive NPV. It is important to stress that in this case, dependence on the grid conditions and price fluctuations is reduced, which is also a great advantage.

As for the apartments, NPVs are still negative. That isn’t as much of a surprising result since their electricity consumption is 36% less than for detached houses, and yet they yield 75% less electricity from PV system installed on their rooftops (initial costs are approximately 50% less).

The main reason for achieving positive results is relatively high incentive price for PV generated electricity. Those were even higher, but recently dropped (as of October 2013). During 2013, the European market continued to transition away from a premium-incentives PV environment towards PV electricity being driven on the grounds of competitive cost. Governments across Europe set in place a series of programmes to expand investment on grid-connected solar power technology. But in face of rapidly declining costs (as already shown on Figure 35) most of these programmes have been tapered. Incentive pricing discontinuation is mostly triggered by reaching grid parity for chosen generation technology.

The term “grid parity” is defined as the moment at which, in a particular market segment in a specific country, the present value of the long-term net earnings (considering revenues, savings, cost and depreciation) of the electricity supply from a PV installation is equal to the long-term cost of receiving traditionally produced and supplied power over the grid.

For example, grid parity for PV was reached in Spain back in 2012. Subsidized prices of solar power in Spain were around nine times more than those of fossil fuels. These prices surely stimulated the market, resulting in Spain installing more solar than the entire rest of world in the boom days in 2007-2008.The stimulus effect of Spain’s program, along with that of Germany (who spent more than two billion Euros to install 30 GW of solar energy capacity), and other European countries, has helped to develop the solar technology and the solar industry for the entire world, leading to falling costs and increasing efficiency [66].

LCOE (levelized cost of energy) is one of the utility industry’s primary metrics for the cost of electricity produced by a generator. It is calculated by accounting for all of a system’s expected lifetime costs (including construction, financing, fuel, maintenance, taxes, insurance and incentives), which are then divided by the system’s lifetime expected power output (kWh). All cost and benefit estimates are adjusted for inflation and discounted to account for the time-value of money. As a financial tool, LCOE is very valuable for the comparison of various generation options. If the cost for a renewable technology is as low as current traditional costs, it is said to have reached grid parity [67].

PV power plants reached LCOE between 0,078 and 0,142 €/kWh in the third quarter of 2013, depending on the type of power plant (ground-mounted utility-scale or small rooftop power plant) and insolation (1000 to 1200 kWh/m^2). The specific power plant costs ranged from 1000 to 1800 €/kWp. The LCOE for all PV power plant types reached parity with other power generation technologies and are even below the average end-customer price for electricity in Germany of 0,289 €/kWh [68].

In the case of detached house without energy storage in Split, break-even price for selling electricity to the grid is 0,1476 €/kWh. This is still too high of a price for Croatia in terms of reaching grid parity. That is why incentive pricing is still needed to support installation of PV systems.

However, there is qualified criticism particularly towards evaluating variable renewables like wind and solar power based on LCOE because it ignores integration costs that occur at the system level. That is why this approach to quantifying PV generation market competitiveness has to be further developed.

7. Conclusion

Today we live in era of great changes as smart technologies will completely transform the way we perceive energy consumption. Lack of generation capacity form conventional resources and climate changes are the main issues of existing power supply system.

With implementation of smart buildings today's centralized electricity generation will transform completely to the point where every smart building owner will produce green energy at the distribution-side of power supply from various renewable resources. This will provide less transmission losses, cleaner energy and optimal operation of the whole system. The latter is enabled by the two-way communication supported by the smart grid.

A cost and benefit analysis for implementing smart households for Norway and Croatia has been conducted. After examination of fifteen various cases of consumption, generation and storage options, it can be concluded that these kinds of projects are still highly dependent on various incentives and feed-in tariffs. Although capital costs are relatively high, they will drop significantly as the technology evolves. As of today, larger scale PV systems have already reached grid parity. This gives positive grounds for further development of such systems on smaller scale.

When it comes to smart buildings, besides consolidating smart metering and renewable energy generation, other functionalities have to be implemented in order to achieve their full potential. Those are primary the means of reducing energy consumption such as demand side management and energy efficiency measures.

When sustainable future is taken as *conditio sine qua non*, smart buildings and smart grid offer an inevitable pathway that leads to whole system operation change. Naturally, such transformation cannot be carried out in a short period of time. Its potential has to be recognized and cherished by this, and generations yet to come.

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